

TITAN'S landscape

New discoveries revealed! p. 30

March 2010

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About Your Professor

Edward B. Burger is Professor of Mathematics and Statistics at Williams College. He earned a B.A. with distinction in mathematics from Connecticut College (summa cum laude)

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Archimedes calculated pi, or the ratio of the circumference of a circle to its diameter, as 3.1418.

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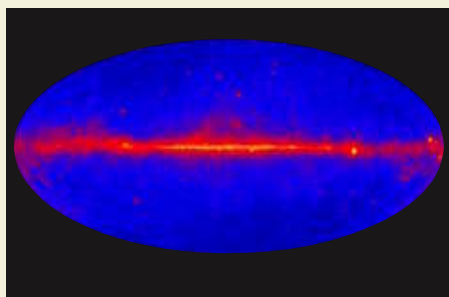


Path of the planets and StarDome.



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NASA's Fermi Telescope discovered a class of pulsars that emit only gamma rays. The energy comes from hot plasma (purple) trapped in the pulsar's magnetic field.

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New visions reveal the violent universe

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This Month in Astronomy



A plea on behalf of obscure targets

by David J. Eicher

Every week, we receive more images of the Orion Nebula, the Andromeda Galaxy, and the Pleiades. We often hear of observations of Jupiter, the galaxy NGC 7331, and the bright planetary nebula in Lyra known as the Ring. This is fantastic, and we celebrate your enthusiastic observations and photographs of the sky every day. I only wish we had even more space in our pages and on our web site to share more images and observations of the sky's wonders.

But I want to make a plea on behalf of the obscure targets of the universe. If we have access to a dark sky, there are so many fascinating objects to observe, to sketch, to image, and to share with our fellow amateur astronomers. Many of us have the telescopes, the cameras, and the skies to go after nearly anything we can conjure up. And the information about what to look at is everywhere — in magazines, books, star atlases, and on the web.

So I'm asking the observers out there, and the imagers, too: Why not take a few nights out of your observing schedule and really push the limits of your scope, your camera, and your eyes? Why not go after one of the Palomar globular clusters, like Palomar 11 in Aquila, an object that glows at 10th magnitude? Catch it, and you'll see a globular cluster that's an impressive 45,000 light-years away.

Maybe you could choose a faint planetary nebula, like one of the 35 obscure ones that lie in the immediate region of the great open cluster M7 in Scorpius. Maybe Haro 1–36 would catch your fancy? It lies in the same field of view as the globular cluster NGC 6441, an object observed often by amateurs.

Maybe you enjoy stars and the amazing, surprising discovery that some stars scattered around the sky are impressively red. How about going after some N-class

carbon stars? These giants have surface temperatures of only about 2500 kelvins and are the coolest of all stars. Maybe Z Piscium or SS Sagittarii come to mind.

If you're more of a galaxy person, you could target a group, an area where you'll find many galaxies congregating together. You might choose something like the NGC 4005 galaxy group in Leo, a cloud containing 15 galaxies glowing brighter than magnitude 16. The cloud's diameter is an impressive 40', larger than the disk of the Moon, and the brightest galaxy, NGC 4005, glows at magnitude 13.0.

Perhaps you're one of those who wants to keep track of the neighbors. Nearby stars, though they may appear as simple, glowing dots, abound in the night sky. If you're in the Southern Hemisphere, you can easily see Proxima Centauri, the nearest star of all (save the Sun, of course), which lies 4.2 light-years away and glows at 11th magnitude. Other nearby stars are many, including Barnard's Star in Ophiuchus, Lalande 21185 in Ursa Major, and Epsilon Eridani. The brightest star in the sky, Sirius, is also one of the closest, but now I've wandered away from my theme of challenges.

In no way am I discouraging you from sending us images of the Orion Nebula or observations of the Hercules Cluster. I'm just suggesting that you might spice up your observing adventures by going after some of the more obscure objects we now know of. And the sky obliges, as it's absolutely loaded with them.

Yours truly,

David J. Eicher
Editor

Astronomy

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View to the past

Thousands of galaxies packed in a sphere spanning some 2 million light-years form Abell 1689, one of the largest galaxy clusters known. Located in central Virgo, Abell 1689 dwarfs its better-known cousin, the Virgo cluster. That cluster lies about 50 million light-years from Earth, while Abell 1689 shines across roughly 2.2 billion light-years. Astronomers estimate that Abell 1689 contains up to 500 trillion times the Sun's mass. All this matter warps the surrounding space, distorting and magnifying the light from more distant galaxies. Albert Einstein predicted this so-called gravitational lensing, which creates the long arcs visible throughout the image and brings into view galaxies up to 10 billion light-years beyond Abell 1689.

ESA/L. Bradley (JHU)/R. Bouwens (UCSC)/H. Ford (JHU)/G. Illingworth (UCSC)

by Karri Ferron

OUR TURN

Jim Kaler

Professor emeritus of astronomy at the University of Illinois at Urbana-Champaign and author of 14 books

What inspired you to write books for the public?

The fun of it. Since I was a kid, I've enjoyed showing people the sky. Writing for the public is just another way of bringing folks to the outdoors to view the heavens, even if vicariously. It was part of a gradual career change in my 40s and 50s, a natural transition from the research itself to describing it to others.

What draws you to study the stars?

Their sheer sparkling beauty on a clear night, from the crackling cold of winter's Orion to the cascades of stars in the summer Milky Way. As much as anything, I find astronomy to be an aesthetic pursuit.

What are some of the coolest things you've done in your career so far?

Observing at the university's old Prairie Observatory out in the country where I could watch the Sun set, see the deer in twilight, and hear the whippoorwills in morning's light. Losing myself in the writing and putting the last sentence on a book. Observing at Kitt Peak and seeing the glow of the zodiacal light go all the way across the sky. Photographing constellations from the Mayall 4-meter Telescope's parking lot while the scope gathered data on M31.

How do you think we can get more people excited about astronomy?

Get them outside to look. Support your local planetarium and

observatory, take your telescope to the sidewalk, or gather the neighbors for a star party. Join an astronomy club and volunteer in schools. Tell the PR people at Hubble, Spitzer, and so on what great jobs they are doing, and explain to your federal legislators how important the scientists' work is.

What do you like to do in your spare time?

Go to concerts and movies. I've long been a runner, though these days I've slowed down a mite. I play some classical guitar and am a pretty good retread trumpet player with an affinity for the baroque. I do much of the family cooking and have a variety of gardens around the house.



Astroideas

The data! We now have large surveys of galaxies in the universe, like the Sloan Digital Sky Survey, and maps of the primordial cosmic microwave background (CMB), including from NASA's Wilkinson Microwave Anisotropy Probe

These maps tell us how smooth or clumpy the universe was at various stages of its early history.

(WMAP). These maps tell us how smooth or clumpy the universe was at various stages of its early history. Because light travels with a finite speed, maps of things farther away are of earlier epochs.

What is the most exciting development in the study of the large-scale structure of the universe?

But why do cosmologists care so much about maps? Consider a chart of the United States in 1790 that shows the population in every square mile. Compare that map with a similar one made today. The story of how the first map evolved into the

second is the story of this country: its history, economics, politics, and sociology. Someone who studies those maps carefully will learn about the constituents of the United States and the forces that govern them. Cosmol-

ogists try to learn similar lessons using maps of the universe.

The best way we currently have of explaining how the universe evolved from its very smooth state depicted in the CMB maps (a snapshot when the universe was just 380,000 years old) to the complex structure observed today is to posit the existence of two mysterious substances: dark matter and dark energy. These two together make up 95 percent of the energy in the universe, but neither has ever been observed directly. I'm working on a bunch of projects now, ranging from studies of stars in the Milky Way to the distribu-

tion of high-energy cosmic rays, but almost all of this work is driven by the urge to understand the dark sector.



Scott Dodelson

Cosmologist at Fermilab in Batavia, Illinois, and professor at the University of Chicago



courtesy Janice Bishop

Janice Bishop

Principal Investigator for the SETI Institute in Mountain View, California

- 7:30 A.M.** Check e-mail at home, answer everything urgent.
- 8:30 A.M.** Leave home to drop off kids at day care.
- 9:30 A.M.** Arrive in the office, check in with three grad students, and review notes for teleconference presentation.
- 10 A.M.** Present new results on minerals detected in Mars images to Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) team via teleconference. Discuss how my group detected the clay minerals, where the clay units are in relation to other rocks in the region, and implications of the differences in clay types for the formation environment on Mars.
- 11 A.M.** Answer e-mail, process paperwork like research grant reports, manage budgets for the multiple research grants my group needs to keep our work funded, and order various materials for the group.
- 12 P.M.** Read science articles on Phoenix Mars Lander results; think about how the identification of carbonates, sulfates, and perchlorates on Mars at the Phoenix landing site fits in CRISM's detection of clays in multiple places around the planet. Consider ideas for future proposals for research funding.
- 2 P.M.** Meet with students to review progress on research — analysis of Mars images, mineral assignments in spectra, coordinating minerals found with environmental conditions on Mars. Prepare figures to illustrate results, work on papers, and prepare presentations.
- 3 P.M.** Measure reflectance spectra in the lab of new beidellite clay samples sent by a colleague to help us determine the types of clays found on Mars in the CRISM data.
- 4 P.M.** Process data and prepare plots comparing the spectra of beidellite clays to spectra of clay-rich units on Mars.
- 5:30 P.M.** Pick up kids from day care.
- 9 P.M.** Edit papers by co-authors to be submitted for publication, papers sent by journals for review, or proposals sent by NASA for review.

Astrofascinations



To learn more about the people featured this month, visit www.Astronomy.com/toc.

What fascinates you most about the star-formation histories of galaxies?

When I was 5, my father and I built a dome on the roof of our house. We would lie up there on summer nights to watch the stars above my home in southern Argentina. My fascination with stars began then. Years later, I earned my Ph.D. on the stellar populations of the Small Magellanic Cloud.

Walter Baade introduced the concept of stellar populations in 1944. He saw, for the first time, individual stars in the center of the Andromeda Galaxy and in its dwarf elliptical companions. The number, brightness, and color of such stars tell us about a galaxy's history. Comparing these observations with models for how stars form and evolve gives us insights into the process of galaxy formation. In some cases, we see evidence for galaxies swallowing smaller galaxies whole; in others, we see evidence for star formation turning on at a particular moment and

then suddenly off again, indicating some environmental trigger. By studying stellar populations, we can learn both about the lives of stars and the lives of their host galaxies.

Today, resolved stellar population studies continue to grow. The arrival of 8-meter telescopes has allowed us to see individual stars in galaxies 3 million light-years away. The next generation of 30- or 40-meter telescopes will extend our ability to observe stars some 60 million light-years away! We'll see many more galaxies and peer backward through time to find out what galaxies looked like 60 million years ago.

Noelia Noel

Marie Curie Postdoc at the University of Edinburgh in Scotland



Justin I. Read (University of Leicester); background: NASA/ESA/The Hubble Heritage Team (STScI/AURA)

Astroinfluences

How did you get interested in astronomy?

As a nuclear engineer for a major U.S. architecture and engineering (A&E) firm, I was always seeking more training and education to satisfy my scientific curiosity. My firm decided to feed my appetite for intellectual pursuits by sending me to get advanced degrees in physics so I could understand more about why things work in addition to how.

I took a graduate astrophysics course that led to other astronomy and astrophysics

courses. My love for science, my instinct to find out why and how things work, my desire to solve astrophysics enigmas, and my passion to explain astronomy and astrophysics in an understandable language to students landed me in my position at the University of Central Florida.

Besides teaching, I analytically and numerically study accretion disks using my engineering and physics backgrounds. Our exoplanet group also observes M dwarf stars using the world's largest telescopes like Keck II to find companions such as brown dwarfs and exoplanets. From time to time, the A&E firm requests my return as a nuclear engineer, but I have found my place in this universe as an astrophysicist.

Michele Montgomery

Physics lecturer and research scientist at the University of Central Florida



Edward Leary; background: NASA

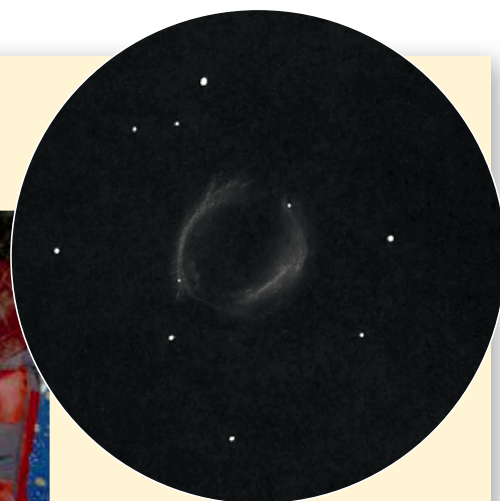
Into the deep

I love David J. Eicher's monthly feature, "Deep-sky Showcase." What a great idea!

I'm a visual observer and astronomical artist. Getting out and enjoying the view has been lots of fun. I have found two books in particular a great inspiration to me: *Deep Sky Reise-führer* ("Deep Sky Travel Guide") by Ronald Stoyan and *Deep Sky Observing* by Steven R. Coe.

I've sent along a sketch I made in September of Jones 1, using white pencil and white pastel on black paper. Keep up the inspiring work! — **Evelyn Petkow**, Munich, Germany

➤ **Evelyn Petkow**, shown here with her Obsession 18 UC telescope, enjoys sketching deep-sky objects to better remember her astronomical experiences. Courtesy Evelyn Petkow



▲ This sketch of Jones 1 features white pencil and white pastel on black sketching paper to depict the ethereal deep-sky object. Evelyn Petkow

October's delights and frights

I thought the October 2009 issue was one of your best from the past few years. I especially liked Stephen James O'Meara's "Ghost Hunt Challenge" and Liz Kruesi's "How we mapped the Milky Way."

Reading the month's "Telescope Insider," though, I found David Nagler's answer about the future of amateur astronomy unusually revealing. He guessed there would be a push toward more dark-sky observation because widespread light pollution has taken away much of the sky's natural awe.

I wonder: What does this saturation of light have to say about our modern times and humanity's timeless fear of the dark? — **Joseph Ashley**, Marathon, Greece

Journey past the center

Bob Berman's column is one of my favorite parts of *Astronomy*. Still, I think

he may have had his numbers off by a factor of two in his October column, "A dozen cool facts," when he said falling through a hole to the other side of Earth takes 90 minutes.

Back at MIT, we studied this phenomenon (known as the Schuler period), and 90 minutes is more than the time it would take to go all the way through to the other side and back again. You wind up on the other side of the planet in about 42 minutes, and back where you started after some 84 minutes (ignoring any drag or Coriolis effects).

Thanks, Mr. Berman, for tickling my imagination in great new ways every month. — **Mike Schimpf**, Pacific Grove, California

You're right. It's the round trip in an airless tunnel through Earth (pole to pole would be the only "practical" way, to avoid hitting the sides) that matches the period of a low Earth satellite or shuttle: 84 minutes or so. In the future I'll be more careful with the stuff I've got scribbled on all those papers on my desk. — **Bob Berman**, Contributing Editor

Stellar vision

Out for our evening walk to a favorite viewpoint last summer, my wife and I viewed a lovely Full Moon rising over the desert near our home in Tucson, Arizona. Suddenly, I was shocked to see three thin, parallel lines drifting across the face of the Moon, which I soon realized were power lines "blocking" my view.

Amazed at their thin, thread-like appearance, and comparing them to lunar features I could see, I estimated

that it would take perhaps 100 of these lines to cover the face of the Moon completely. Somewhat later, I returned to the spot and measured the distance to the wires to be 180 yards (165 meters). A sample of wire hanging down from the lines measured only 0.2 inch (5 millimeters) in diameter.

A quick calculation yielded an astonishing angular resolution from my position of only 0.1 arcminute (or 6 arcseconds), far below Dawes' limit for the naked eye! Al Nagler, in his 1991 article "Choosing your Telescope's Magnification," postulated that naked-eye resolution is about 1 arcminute.

However, Thomas Dobbins noted in his 1988 book *Introduction to Observing and Photographing the Solar System* that the eye's ability to resolve a fine dark line on a bright background is much greater than this. He cites experiments by Pickering that indicate the Dawes limit may be exceeded by a factor of 5 and perhaps up to a factor of 14 under optimal conditions.

I guess I don't have superlative vision after all. — **E. William Gates**, Tucson, Arizona



October 2009

We welcome your comments. Send letters to *Astronomy Letters*, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.



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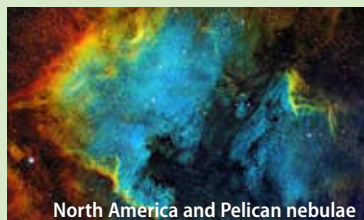
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Strange Universe

by Bob Berman

It wasn't there

Gaining lessons and humility from astronomy's illusions.

You know the old Hughes Mearns poem, "As I was going up the stair, I met a man who wasn't there ..."

Astronomers study objects we *assume* are really there. But sometimes they're not. A few months ago we mentioned rainbows, which stirred some controversy. Are they *there*? Sort of. A rainbow is nothing but a group of light rays converging on your eyes. It has no solidity. It cannot cast a shadow.

But its colors are real, right? Well, colors are pulses of magnetism and electricity. By themselves they have no visual properties. When nobody's looking, neither Mars nor a rainbow has color. Rather, we animals respond to the invisible electromagnetic stimulation; our retinas and brains conjure the experience of spectral colors. They're not out there on their own.

Solids are the same. Our fingers perceive the push of electrical repulsive forces when we touch a stone. We regard it as solid because we can't penetrate the rock or see through it. But we never contact a solid. Rather, we feel energy fields.

Telescopes transport us beyond our local illusions to reveal new, larger ones. Is the Sun really a yellow star out there, as textbooks claim? Not at all. Astronauts report it's as white as snow. The lemony color we ground-dwellers perceive is merely some of its blue light scattered through our atmosphere to give us our blue sky. The remaining dominant colors, green and red, combine into yellow — an atmospheric artifact.

What about red giants? Are they red? Look at Betelgeuse. It's yellow-orange. Nobody has ever observed a red giant star that is actually red. And the low, enormous Moon: Is this "Moon illusion" caused by our atmosphere enlarging it, as

many believe? Nope. Appearances notwithstanding, the Moon is measurably smaller when it's on the horizon because it's then farthest from you.

Wow, there goes a meteor across the sky — except you never saw it. Nobody can see something the size of an apple seed at a distance of 70 miles. What you really saw was the hot glowing air surrounding the particle.

Look at the beautiful Orion Nebula (M42) using SLOOH, which is a live, public way to see the true colors of deep space. (Disclosure: I'm involved with that online observatory.) Because SLOOH neither enhances nor fakes M42's colors, it's what astronauts would see if they

tive layer. Below it, humanoid creatures frolic on the Sun's pastoral surface.

The brilliant Harlow Shapley spoke for many astronomers when he argued in 1920 that external galaxies do not exist. All those spirals, he insisted, are just small clouds of nearby gas.

Strange Neptune motion made scientists search for a massive Planet X for half a century. But Pluto, found later, wasn't it. Planet X was imaginary. Neptune's seeming irregularities were a mistake.

In 340 B.C., Heraclides said that our planet spins. The idea was dismissed for nearly 2,000 years. "If Earth rotated," idiots argued, "a person jumping up would land in a different spot."

The list of celestial sure-bets that weren't there is endless. Nineteenth-century astronomers declared nebulae to be made of an unearthly substance called nebulium. Ten generations of scientists insisted space is filled with ether. People envisioned Venus as a comfortable place. And until just a dozen years ago, every astronomer *knew* the universe's expansion was slowing down.

Nor is high IQ any armor against error. Aristotle called Earth the center of the universe. Newton believed in alchemy. Kepler in astrology. Einstein wrongly dismissed the spooky realities of particle entanglement. Hawking said time could travel backward, and then changed his mind as if to demonstrate the process.

As science grows at an awesome pace, some claim we'll soon find a "Theory of Everything." More likely, knowledge will advance in spurts and detours. Error and illusion will continue to be part of human experience. And our children will grow up to find that some of today's sacred certainties have vanished like the ether. ☛

The list of celestial sure-bets that weren't there is endless.

could travel the 1,500 light-years and stare it in the face. Right? Not really.

A nebula that looks gray through a backyard telescope would appear the same in person. Reason: As you approach the gas cloud, it spreads out and diffuses so that the intensity per square degree barely budes. Your retina continues to employ its low-light, black-and-white vision. Galaxies and nebulae will never show their magazine colors to visitors. So are the colors there or not? Your call.

Astronomers have a long history of imagining all sorts of things that weren't there. William Herschel, discoverer of Uranus, believed that beneath the Sun's supposed luminous clouds lies a protec-



Browse the "Strange Universe" archive at www.Astronomy.com/Berman.

Contact me about my strange universe by visiting skymanbob.com.



Observing Basics

by Glenn Chaple

Sketching 101

Use a pencil and paper at the eyepiece to hone your observing skills.

"But I can't draw!"

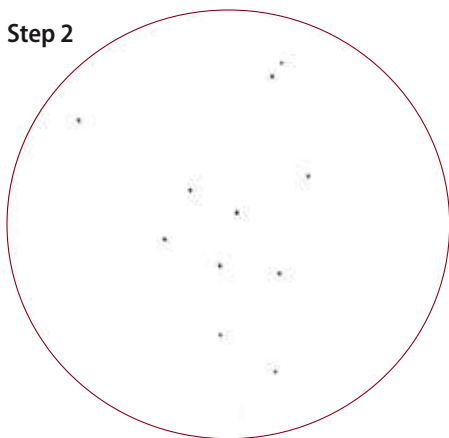
It's a complaint many an art teacher is all too familiar with. Perhaps you had the same thought upon discovering that our topic this month is astronomical sketching.

Sketching at the eyepiece isn't as hard as you might think, as long as you don't rush. Besides a telescope and eyepieces, you'll need a clipboard, a sheet of paper with a circle on it to represent the field of view, and a few sharpened #2 pencils with erasers. You'll also need a flashlight covered with red cellophane to preserve your night vision. Armed with these tools, you're ready! Here's how to create your own cosmic masterpiece.

Step 1

Center the subject (in this case, we'll work with the Beehive Cluster [M44]) in the eyepiece's field of view. Use a magnification that captures the entire cluster, as well as some of the surrounding space.

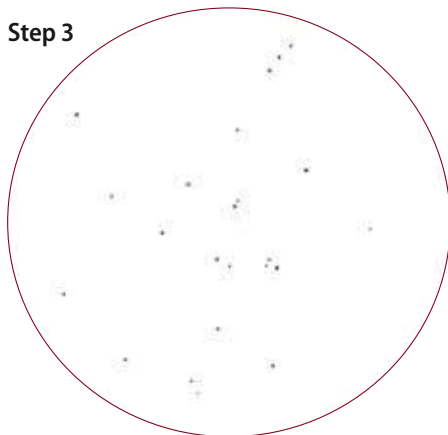
Step 2



Step 2

Begin by sketching "anchor" stars. These bright stars serve as reference points in your sketch. Carefully draw each star, noting its position in the field relative to the center and edge. It helps to think of the field edge as the face of a clock, with stars near the top marking the 12 o'clock position. Look for distinct star patterns like triangles or curved lines. As you add each star, note its position in relation to the ones already sketched. Because you'll represent a star's brightness by the size of the pencil dot you draw, make these dots fairly large and bold.

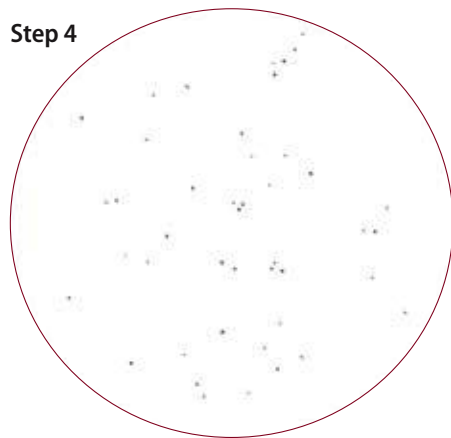
Step 3



Step 3

Add the fainter, but readily visible, member stars of the Beehive Cluster. Use the anchor stars to position them. Because you're sketching fainter stars, the pencil dots should be less bold.

Step 4



Step 4

Here's the part that hones your observing skills. Look carefully for faint stars that approach the limiting magnitude of your telescope (averted vision helps here). Represent each with tiny pinpoints.

Sketching may not be as fast and accurate as digital photography, but it forces you to take a good long look at your subject. You pick out subtle nuances you might miss with a casual glance.

Step 5

Your masterpiece is complete! All it needs is a title (in this case, "M44"), the date and time, the telescope you used, the eyepiece's magnifying power, and sky conditions.

Questions, comments, or suggestions? E-mail me at gchaple@hotmail.com. Next month: A funny thing happened on the way to the observatory. Clear skies! ☼



Browse the "Observing Basics" archive at www.Astronomy.com/Chaple.

Learn more sketching techniques

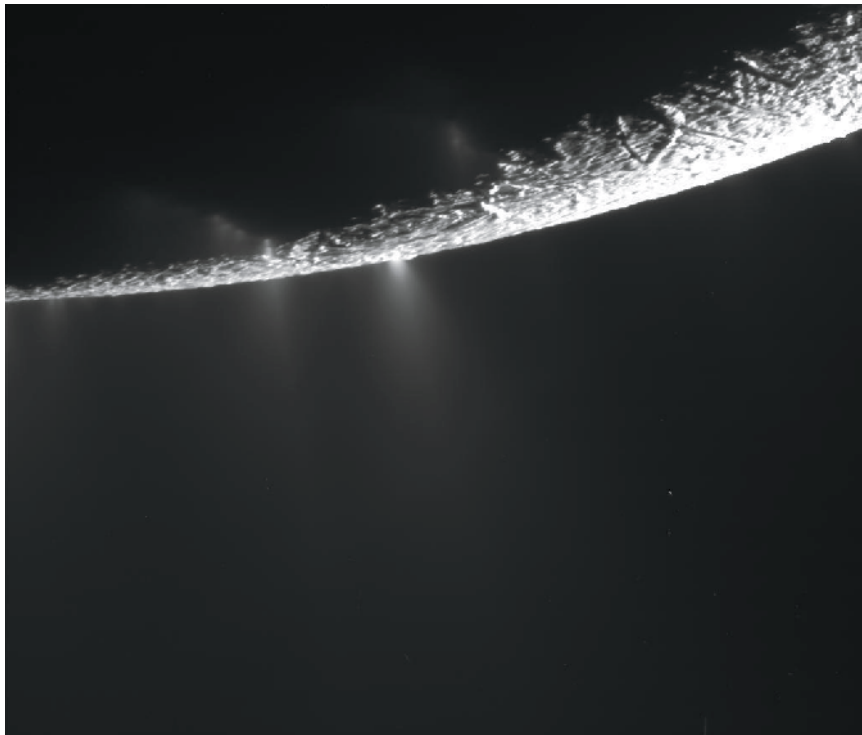
For further information on astronomical sketching, be sure to follow David J. Eicher's "Deep-sky Showcase" in each issue of *Astronomy* (page 68 this month). You can observe the objects he suggests and compare sketching results.

For more Internet resources, log on to Bill Greer's astronomy site at www.rangeweb.net/~sketcher. In addition, look into Math Heijen's how-to at www.backyard-astro.com/focusonarchive/sketching/sketching.html. For a video clip featuring Dave Eicher, subscribers can visit www.Astronomy.com/videos. Click on "How to," and scroll down toward the bottom to get to "Sketching from the telescope."

Finally, from Patrick Moore's Practical Astronomy Series comes an excellent book, *Astronomical Sketching* (Springer, 2007). You'll find in-depth instruction on a variety of astro-sketching techniques from authors Richard Handy, David B. Moody, Jeremy Perez, Erika Rix, and Sol Robbins.

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Zoom by a plume. Cassini captured this unprocessed image of the plumes at Enceladus' south pole during its November 21 flyby. NASA/JPL/Space Science Institute

Cassini visits Enceladus twice

NASA's Cassini mission flew by Saturn's moon Enceladus twice in November, on the 2nd and then the 21st. During the first flyby, the craft plunged deeper than ever before through the moon's plumes at the south pole.

Scientists are mostly interested in Enceladus' "tiger stripes." These fissures spew jets of water vapor and other particles, but researchers aren't sure of the jets' compositions. The November 2 dive into the plumes allowed the craft to taste the material spewing out. This will help astronomers determine what makes up the plumes.

Scientists will use images taken during the November 21 flyby to create the most detailed mosaic image yet of Enceladus' southern region. This flyby marked scientists' last look at the tiger stripes for several years, as the south polar region is entering winter. — **LIZ KRUESI**

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'Dropout' method pinpoints oldest galaxies

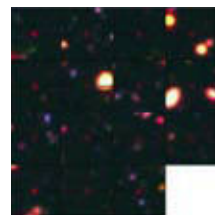
A team of American and Japanese astronomers recently found 22 of the earliest known galaxies in the universe and determined that one formed just 787 million years after the Big Bang. With current estimates of the universe's age of 13.7 billion years, that makes this galaxy around 13 billion years old. The team, led by Masami Ouchi of the Carnegie Observatories, published its work in the December issue of *The Astrophysical Journal*.

To find these extremely old and distant galaxies, Ouchi explains, the team looks for a type of object it calls a dropout galaxy. "We use progressively redder filters that reveal increasing

wavelengths of light, and watch which galaxies disappear from, or 'drop out' of, images made using those filters."

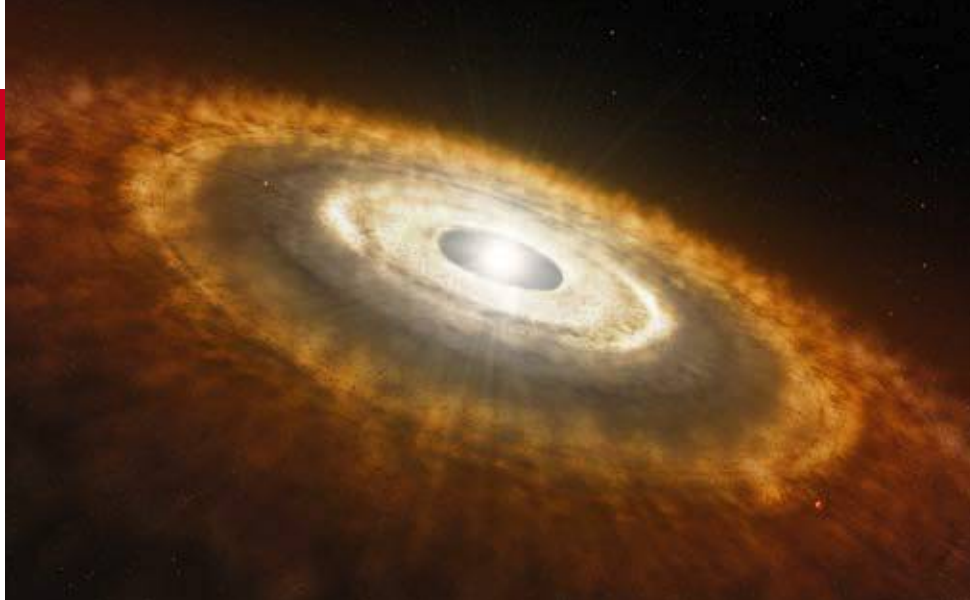
Because the faraway galaxies have such tremendous redshifts, they're the first to disappear when the scientists use their reddest filters.

"What makes this study different," Ouchi continues, "is that we surveyed an area that is over 100 times larger than previous ones and, as a result, had a larger sample of early galaxies (22) than past surveys." He adds that because they used the same dropout technique to identify all the galaxies, they're likely to be approximately the same age. — **BILL ANDREWS**



Dropout décor. Scientists estimate the Subaru Deep Field galaxies found with the dropout method, shown in a false-color composite image, are around 13 billion years old. Masami Ouchi and

The Astrophysical Journal



Lithium stealer. Sun-like stars that host planets, like the one in this artist's impression, have less of the element lithium than those that don't host planets. ESO/L. Calçada

Astronomers solve stellar mystery

A team of astronomers used the European Southern Observatory's HARPS spectrograph to study the light from 162 stars with temperatures — and therefore masses — similar to the Sun's. Of those Sun-like stars, 46 host planets. The team found that the planet-hosting stars have significantly less lithium than the 116 "single" stars. The finding appeared in the November 12 issue of *Nature*.

Scientists believe lithium was created just minutes after the Big Bang. Stars don't create significant amounts of this element. So unless stars have been destroying it, all stars should have similar amounts of lithium. But for decades researchers have known that the Sun has much less lithium than other stars of similar age and mass; yet they didn't know why.

Astronomers, led by Garik Israelian of Spain's Instituto de Astrofísica de Canarias in Tenerife, found that the 46 Sun-like stars with planetary systems have lithium abundances similar to the Sun. The 116 non-planet-hosting stars had lithium levels some 10 times greater.

The team isn't sure what could cause this difference. However, one idea is that protoplanetary dust disks may "spin up" the star as the disk rotates. This would mix the star's elements, plunging lithium farther into the star. The star's nuclear furnace would then destroy more of this element.

The lithium difference might also aid in extrasolar planet searches by encouraging astronomers to focus on stars with lower lithium abundances. — L. K.



NASA/ESA/SSC/CXC/STScI

Observatories release great image of our galactic center

Striking view. To commemorate the International Year of Astronomy 2009, the Great Observatories released a composite image of the Milky Way's center November 10. The never-before-seen view combines Hubble Space Telescope's near-infrared, Spitzer Space Telescope's infrared, and Chandra X-ray Observatory's X-ray exposures. The white portion to the right and just below the middle of the image is our galaxy's turbulent center. The composite's width is about $\frac{1}{2}^\circ$ — the size of the Full Moon. — L. K.

UTAH'S FIRST LIGHT

The University of Utah celebrated its new 32-inch reflecting telescope's initial observations, of spiral galaxy NGC 891, November 11.

MEDIUM BLACK HOLE

An X-ray source in the galaxy NGC 5408 may be an elusive middleweight black hole, harder to find because of its unextreme nature, NASA scientists stated November 10.

FREE MARS SPIRIT!

NASA began attempts to free one of its Mars rovers, Spirit, from its sandy trap of the past 8 months, November 16.

SECOND RETROGRADER

HAT-P-7b is the second exoplanet to have a retrograde or highly tilted orbit, according to studies in the October *Astronomical Society of Japan Letters* and *The Astrophysical Journal Letters*.

OLD OBJECT, NEW NAME

The International Astronomical Union has designated asteroid 84447 as Jeffkanipe, after the science writer.

EXPLOSIVE NEWS

ESO's Very Large Telescope revealed that binary system V445 is likely to explode as a type Ia supernova, according to a paper in the November 20 *The Astrophysical Journal*.

HUBBLE PARTS' NEW HOME

NASA presented the Smithsonian's National Air and Space Museum with two key instruments (since replaced) from the Hubble Space Telescope November 18.

DARKEST SKIES

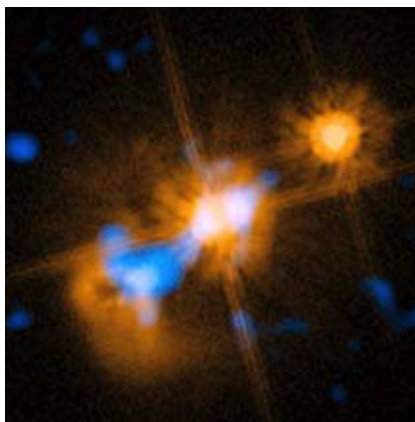
The International Dark-Sky Association awarded Scotland's Galloway Forest Park "Dark Sky Park" status, the highest achievable distinction from the association, November 16.

GALACTIC GAMBLING

Galaxy Zoo Mergers went live November 24, letting anyone contribute to science by comparing images of colliding galaxies with simulated ones on a "cosmic slot machine."

MICROGRAVITY MICROBES

Shuttle mission STS-129, which launched November 16, took microbes into orbit as part of an experiment designed by Texas Southern University students.



Lonely quasar. Scientists studying the only known quasar without a host galaxy, HE0450-2958, may be one step closer to understanding how galaxies form. ESO

Galaxy builder?

European scientists may have finally answered the cosmic version of the "chicken or the egg" conundrum: Which came first, galaxies or the supermassive black holes in their centers?

David Elbaz and Knud Jahnke, each the lead author of a forthcoming paper in, respectively, *Astronomy & Astrophysics* and *The Astrophysical Journal*, used the European Southern Observatory's Very Large Telescope to study quasar HE0450-2958. A quasar, or quasi-stellar radio source, is a highly energetic and distant energy emitter, typically thought to be the black hole and surrounding central region of a large galaxy. But HE0450-2958, approximately 5 billion light-years away, is the only known quasar without a host galaxy surrounding it.

Astronomers had suspected large dust clouds of possibly hiding HE0450-2958's host galaxy, but Jahnke's observations found none. "Instead," he says, "we discovered that an apparently unrelated galaxy in the quasar's immediate neighborhood is producing stars at a frantic rate."

"Our study suggests that supermassive black holes can trigger the formation of stars, thus 'building' their own host galaxies," says Elbaz. HE0450-2958 was already known to shower that companion galaxy with highly energetic particles and a stream of fast-moving gas, providing it with both matter and energy, and supporting the idea that the quasar creates its own host galaxy.

Elbaz continued: "Although the quasar is still 'naked,' it will eventually be 'dressed' when it merges with its star-rich companion. It will then finally reside inside a host galaxy like all other quasars." — **B. A.**

Rosetta leaves no stone unturned

On November 13, the European Space Agency's Rosetta spacecraft made its third and final flyby of Earth. The probe passed 1,542 miles (2,481 kilometers) above a spot just south of the Indonesian island of Java at 2:46 A.M. EST. At the time, Rosetta was moving at 29,800 mph (48,000 km/h).

The main purpose of the flyby was to boost Rosetta's speed by stealing a little of Earth's orbital energy. Mission accomplished. Rosetta left Earth's vicinity traveling 8,100 mph (13,000 km/h) faster than when it came in. The probe now has enough energy to reach its ultimate target: Comet 67P/Churyumov-Gerasimenko.

Mission controllers turned on several of Rosetta's 11 science instruments for the Earth flyby. The probe's imaging system took a series of 24 photos, one each hour, with its narrow-angle camera. Scientists also studied Earth's atmosphere and magnetosphere and searched for aurorae on Earth and water on the Moon.

Rosetta is now nearly two-thirds of the way to Comet 67P/Churyumov-Gerasimenko, having traveled 2.8 billion miles (4.5 billion km) of its 4.4-billion-mile (7.1 billion km) journey. It will fly past asteroid 21 Lutetia in July and go into hibernation by mid-2011 during the coldest part of its trip. Mission controllers will wake up Rosetta in spring 2014 to prepare for the comet rendezvous.

Rosetta isn't the first spacecraft to visit a comet, but it will be the first to rendezvous with one of these relics from the early solar system and follow it for more than a year. The probe will reach 67P/Churyumov-Gerasimenko as the comet speeds toward the Sun, then study what happens as it comes closest to the Sun and then moves away. The comet orbits the Sun every 6.6 years at a distance that varies from 116 million miles (186 million km) to 533 million miles (857 million km).

In addition, Rosetta has a small lander that will set down on the comet's icy nucleus, which Earth-based observations show measures about 2.5 miles (4 km) across. The lander will explore the comet's surface with a suite of nine science instruments. Once Rosetta wraps up its mission in late 2015, astronomers hope to better understand how comets work and what they have to say about the solar system's origin and evolution. — **RICHARD TALCOTT**



Thin crescent. Rosetta snapped this portrait of Earth from a distance of 217,000 miles (350,000 km). Parts of Antarctica and South America show up beneath the clouds. ESA



South Pacific. A huge anticyclone swirls in the South Pacific in this photo from Rosetta's narrow-angle camera. ESA



ESO/F. Ferraro

Two-sided. Globular star cluster Terzan 5 sits in our galaxy's central bulge. The cluster harbors stars of different metallicities and therefore ages.

Globular clusters might be galaxy relics

Astronomers have dug up evidence that not all the stars within some globular clusters (dense stellar conglomerations) are the same age or have the same composition. These findings imply that some globular clusters may be relics of dwarf galaxies. Two papers profiling two different teams' results appeared in the November 26 issue of *Nature*.

One team used the European Southern Observatory's Very Large Telescope to study Terzan 5, a globular cluster at the Milky Way's core. The team, led by Francesco Ferraro of the University of Bologna in Italy, found that the cluster contains two populations of stars — one about 12 billion years old, and the other just half that age. It studied the amount of heavy elements (or "metals") in a number of stars within Terzan 5.

The team thinks some stars in the older population exploded as supernovae. Then the younger group formed out of this metal-enriched gas. A star's metal ratio can help astronomers determine a rough age. Terzan 5's younger group has about 3 times as much iron as the older group.

Before this finding, scientists knew of only one other globular cluster that had stars of varying metal content, Omega Centauri.

Jae-Woo Lee of Sejong University in Seoul, Korea, and colleagues studied 37 globular clusters and found that about half contain stars that have varying calcium abundances. Lee's group concludes that these stars likely formed from material spewed from supernovae. These stellar populations are from different epochs.

Both teams' findings will help astronomers piece together how the Milky Way formed. "The history of the Milky Way is encoded in its oldest fragments, globular clusters, and other systems of stars that have witnessed the entire evolution of our galaxy," says Ferraro. — L. K.

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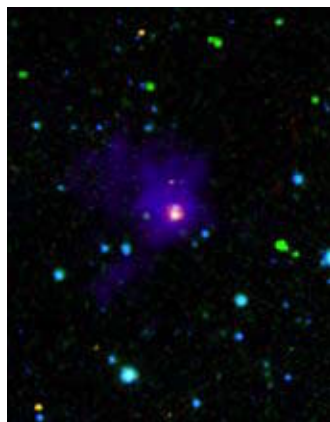


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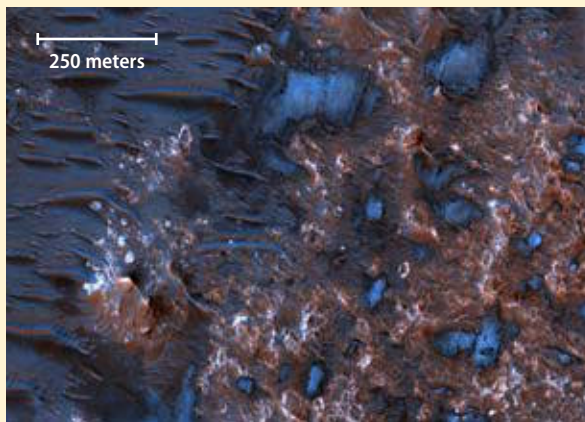
Baby brown dwarf. Two brown dwarf stars, potentially the youngest ever discovered, lie in an envelope of cool dust (in purple) at the center of this image from NASA's Spitzer Space Telescope.

Brown dwarf mystery solved

Brown dwarfs have always been troublesome for scientists. With temperatures and masses falling somewhere between normal planetary and stellar ranges, astronomers have wondered just how one forms — like a planet, or like a star?

A paper in a December issue of *Astronomy & Astrophysics*, analyzing what might be the youngest brown dwarfs ever seen, suggests they form like low-mass stars. The authors used data from NASA's Spitzer Space Telescope (before it ran out of coolant in May 2009 and began its "warm" mission) to comb through the dark cloud Barnard 213 in the Taurus-Auriga complex. This is a region well-known to astronomers for harboring young objects.

"We decided to go several steps back in the process when [brown dwarfs] are really hidden," says David Barrado of the Centro de Astrobiología in Madrid, Spain, lead author of the paper. Because young brown dwarfs evolve so quickly, astronomers had never been able to unambiguously find one in its early stages of formation since their first discovery in 1995. — **B. A.**



Near a delta's edge

Cratered land. One proposed landing site for the Mars Science Laboratory (MSL), scheduled to launch 2011, is Eberswalde Crater. This High Resolution Imaging Science Experiment (HiRISE) image, released November 18, shows the crater's edge. Eberswalde Crater is a possible MSL landing site because it's an ancient river delta. Orbiting spacecraft have detected clay minerals within the crater sediments, evidence of past water activity. — **L. K.**

NASA/JPL/University of Arizona

BRIEFCASE

New kind of star found

A team of astronomers discovered two white dwarfs, certain dense stellar remnants, that have way too much oxygen. The astronomers say these are likely failed supernovae and may be the endpoint of stars that are between 7 and 10 solar masses. Less massive stars end their lives as normal white dwarfs; more massive ones explode as supernovae. The findings appeared in the November 13 issue of *Science*. — **L. K.**

Young interacting binary caught

Astronomers reported in the November 20 *Science* that they have captured a direct image in the infrared of protoplanetary disks around stars in a binary star system. The scientists observed a bridge of infrared-emitting material between the two disks. They used the Subaru 8.2-meter telescope atop Mauna Kea for the observation. — **L. K.**

Phoenix seen in images

The High Resolution Imaging Science Experiment (HiRISE) aboard the Mars Reconnaissance Orbiter imaged the Phoenix Lander at the end of the martian winter. A sheet of frost covered the 4.9-foot-diameter (1.5 meters) craft. Researchers released the image November 2, roughly a year after Phoenix went silent. — **L. K.**

25 years ago in Astronomy

In the March 1985 issue of *Astronomy*, astro-imager Robert Reeves divulged some tips and techniques that go into "Making an Astrophotographic Mosaic."

While creating a mosaic from different astroimages remains an arduous task today, Reeves' detailed explanations show how much harder it was before the days of digital cameras and image correction software. "You must assemble the mosaic photos on a spherical surface whose diameter, based on the size of the photos, equals that of the celestial sphere. ... Print the mosaic pieces in the order they will appear on the finished product. This allows you to match the density of succeeding prints so none will stand out as too light or dark."

Despite the hardships, Reeves wrote, it is sure to bring "pride in your photographic craftsmanship, and fun!"



March 1985



March 2000

10 years ago in Astronomy

In the March 2000 issue of *Astronomy*, exoplanet sleuths Geoff Marcy and Paul Butler examined the role of extrasolar planets in astronomy. Marcy and Butler were uniquely qualified to write "Hunting Planets Beyond"

because they led a team that discovered or co-discovered 19 exoplanets, more than half of the 33 then known.

"Surely there must be many lukewarm worlds that can host complex organic chemistry," they wrote, though 10 years and more than 400 exoplanets later we still don't know of any. "The time is not far off when we can replace the artists' conceptions of extrasolar planets with photographs of the planets themselves and gaze upon landscapes as bizarre and unexpected as those on our nine planets."

Alas, not only are we still some years away from such a sight, but we've also lost a planet in the process! — **B. A.**



Hot stuff. Cygnus X-3 consists of a hot, massive star orbited by either a neutron star or black hole embedded within a disk of material. Astronomers have discovered that this object emits gamma rays in addition to X-rays and radio waves. NASA's Goddard Space Flight Center

Cygnus X-3 emits gamma rays

Astronomers from two gamma-ray space observatories have reported detecting gamma rays from microquasar Cygnus X-3. This object is a binary system composed of a hot, massive star paired with a compact object (either a neutron star or black hole) embedded in a disk of material. The team that used Italy's AGILE spacecraft published its findings in the November 22 issue of *Nature*. The Fermi Gamma-ray Space Telescope's team published its findings in the November 27 *Science*.

For decades, astronomers have detected X-rays and radio waves from Cygnus X-3, but these reports are the first confirmed gamma-ray emission observations.

Both teams observed a pattern to the gamma radiation. The Fermi team observed a signal that strengthened every 4.8 hours. This is the same amount of time it takes the binary companion to complete one orbit. The AGILE team observed gamma-ray flares shortly before radio jets.

Neither group fully understands what causes the gamma rays. However, these observations provide clues as to what accelerates gamma rays to such extreme energies. — L. K.

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ESA/R. O'Connell (University of Virginia)/Wide Field Camera 3 Science Oversight Committee/Hubble Heritage Team (STScI/AURA)

Star birth in M83

Into the Pinwheel. The Hubble Space Telescope imaged spiral galaxy M83, nicknamed the Southern Pinwheel, in August 2009. Hubble's new camera, the Wide Field Camera 3, captured in the curving arms one of the most detailed views of star birth ever, released November 5. The picture also depicts young star clusters, ancient globular star clusters, and hundreds of thousands of individual stars, mostly blue supergiants and red supergiants. The galaxy's core appears as a whitish region to the far right. — B. A.

Heavy elements spied

Astronomers with the Suzaku X-ray observatory have discovered the largest known reservoir of heavy elements in the universe. The satellite detected chromium and manganese in the central region of the Perseus galaxy cluster. This was also the first time the elements have been detected in a cluster, added study leader Takayuki Tamaura of the Japan Aerospace Exploration Agency. The findings appeared in the November 1 issue of *The Astrophysical Journal Letters*.

The chromium and manganese atoms are in the intergalactic material (IGM) between galaxies. The IGM is extremely hot and radiates energy as X-rays. Suzaku split apart the cluster's X-ray emission into its component wavelengths, called a spectrum. The spectrum contains information about the type and amount of elements in the intergalactic material.

While hydrogen and helium were created just after the universe began, heavier elements are more difficult to forge. They require the pressures within massive stars. After these stars die in explosions called supernovae, the winds from the explosions disperse the material and even push it out of individual galaxies into the IGM. The astronomers found that within the Perseus cluster lies so much chromium and manganese that it would have taken some 3 billion supernovae to create the elements. — L. K.

LHC breaks energy record

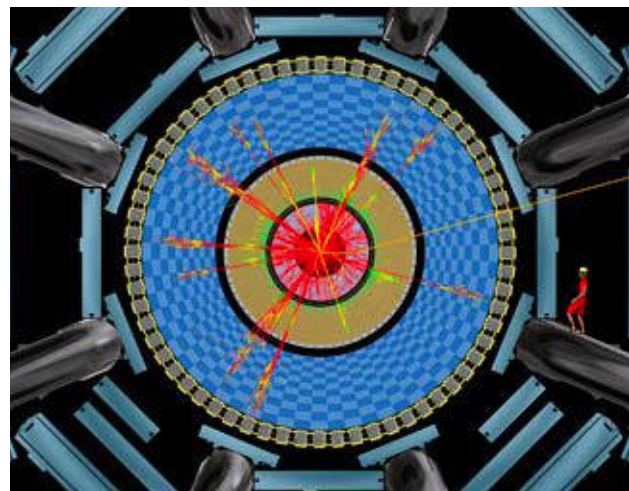
The European Organization for Nuclear Research (CERN) broke a world record with its Large Hadron Collider (LHC) in the early hours of November 30. By accelerating its twin proton beams to 1.18 trillion electron volts, or teraelectron volts (TeV), the LHC became the world's highest-energy particle accelerator, beating the American Fermi National Accelerator Laboratory's previous record of 0.98 TeV.

"We are still coming to terms with just how smoothly the LHC commissioning is going," says CERN Director General Rolf Heuer. The so-called atom smasher achieved the new record just 10 days after it restarted, and just 7 days after it circulated two proton beams together for the first time. That milestone, on November 23, also marked the first time

the LHC's four detectors recorded any collision data.

CERN's scientists hope the collider's smooth progress will continue all the way toward their objective of first physics early in 2010, at a collision energy of 7 TeV (3.5 TeV per beam). Still, that didn't stop a group from submitting a paper to the *European Journal of Physics* just six days after the first collisions, which it accepted for publication on December 1. The paper mainly described how the ALICE particle detector confirmed theories and previous experiments.

"[The LHC's progress] is fantastic," says Heuer. "However, we are continuing to take it step by step, and there is still a lot to do before we start physics in 2010. I'm keeping my champagne on ice until then." — B. A.



Smashing, chaps! The LHC's ATLAS detector, illustrated here with two protons colliding, was the first to spot particle collisions November 23, just a week before the collider became the world's highest-energy particle accelerator. European Organization for Nuclear Research



Stellar powderkeg. Helium flows from one white dwarf to another in this artist's impression, piling up helium which may eventually explode into a type Ia supernova. Tony Piro

New supernova type detected

Astronomers observed a new type of supernova previously thought only theoretically possible. Dovi Poznanski of the University of California, Berkeley and colleagues analyzed a 2002 supernova and determined it is different from any observed before. The paper appeared in the November 5 issue of *Science*. Normally, a supernova results either from an exploding white dwarf star or the collapse of a highly massive star.

Poznanski and his colleagues found that SN 2002bj didn't fit in either category due to its relative faintness, quick life span, and scattering of elements not usually associated with supernova explosions.

"This is the fastest evolving supernova we have ever seen," said Poznanski. "Its brightness just dropped like a rock."

Helium detected in SN 2002bj's spectrum links it to a type of supernova, dubbed .Ia ("point one A"), previously only theoretically possible, which erupts from the detonation of helium on a white dwarf. This explosion would last only one-tenth as long and shine only one-tenth as brightly as its distant cousin the type Ia supernova, the familiar type of white dwarf supernovae.

The theory suggests that occasionally in a binary star system, helium might flow from one white dwarf onto another. Eventually, after enough helium gathers, it will ignite as a thermonuclear explosion that throws into space any remaining excess helium, along with the unusual radioactive elements formed in the process.

Poznanski said he is confident new surveys will detect more type .Ia supernovae, despite their rarity, by scanning bigger, more distant parts of the sky. — **B. A.**

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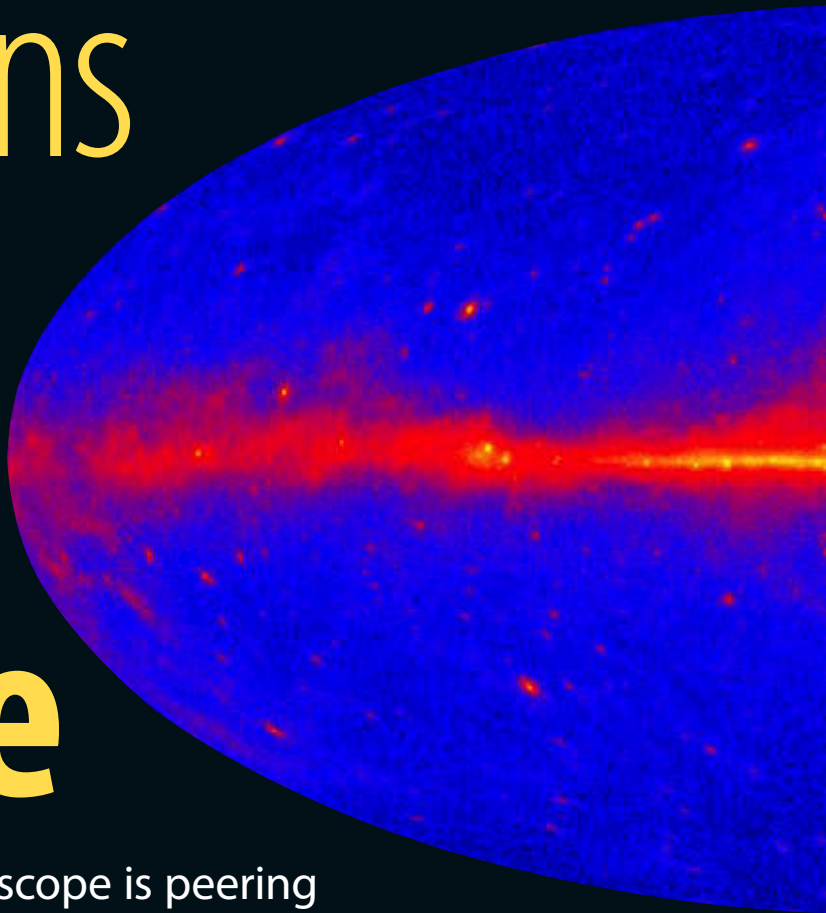
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New visions reveal the violent universe

The Fermi Gamma-ray Space Telescope is peering into active galaxies, pulsars, and gamma-ray bursts — and even quantum gravity. **by Francis Reddy**



After a year and a half in space, NASA's Fermi Gamma-ray Space Telescope has delivered the deepest, best-resolved, and most detailed view ever of the extreme universe. The observatory watches pulsars old and young, gamma-ray bursts, and flares from massive black holes in galaxies billions of light-years away.

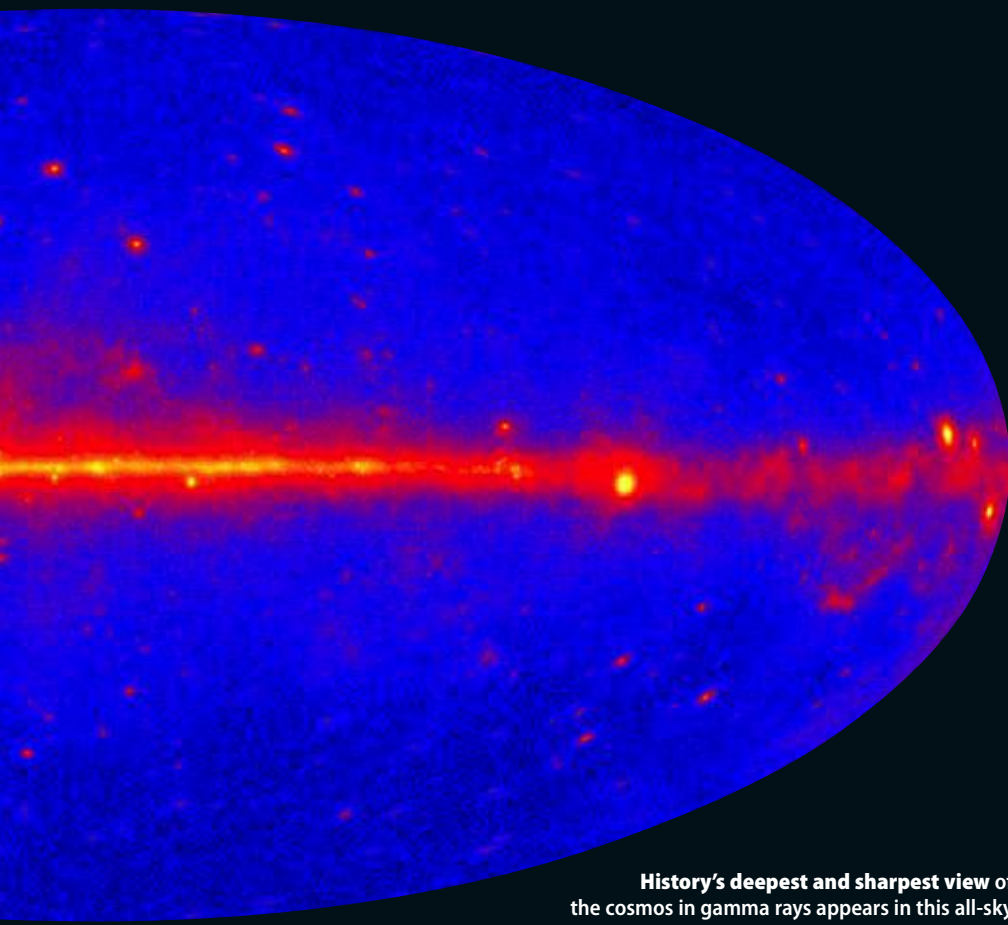
These and other signals from the gamma-ray sky carry a taste of phenomena more energetic than anything scientists can create on Earth. The high-energy

radiation also allows researchers to explore key areas in cosmology and fundamental physics. "This is a huge discovery space that we're just beginning to probe," says Peter Michelson, the principal investigator on Fermi's Large Area Telescope (LAT) at Stanford University in California. "As the LAT sky exposure builds up with time, we are seeing deeper and deeper into our universe with unprecedented detail."

Light, on steroids

Gamma rays share kinship with radio waves, visible light, and X-rays because they, too, are part of the electromagnetic spectrum. With wavelengths of a few trillionths of a meter — the size of an atom

Riding a Delta II booster, Fermi lifts off from Pad 17-B at Cape Canaveral Air Force Station, Florida, June 11, 2008. United Launch Alliance/Carleton Baillie



History's deepest and sharpest view of the cosmos in gamma rays appears in this all-sky map from Fermi's first year of data. The image shows the rate at which Fermi's Large Area Telescope captured gamma rays with energies greater than 300 MeV, or some 150 million times greater than that of visible light; brighter colors equal higher rates. NASA/DOE/Fermi LAT Collaboration

and smaller — gamma rays sport the highest frequencies and energies of the spectrum. Put simply, gamma rays are the highest-energy form of light.

In fact, the gamma-ray portion of the electromagnetic spectrum spans a broader energy range than all other parts combined. Scientists express this energy in terms of a unit called the electron volt (eV), defined as the energy an electron gains as it moves through an electrical potential of 1 volt. Visible light falls between about 2 and 3 eV. Dental X-rays clock in at about 60,000 eV. Entry-level gamma rays sport twice this energy; their more energetic brethren, trillions of times more. Luckily for life on Earth, our atmosphere shields us from gamma rays.

The notion of gamma-ray astronomy dates back to 1958 and theoretical astrophysicist Philip Morrison, then at Cornell University. He reasoned that visible light — the very basis of observational astronomy — was essentially a secondary phenomenon. Stars shine because nuclear reactions in their cores produce gamma rays, which heat stellar gases to incandescence. Other high-energy processes also produce gamma rays, and Morrison worked out the types of objects that might emit them.

Long adolescence

Even though the work of Morrison and others spurred immediate interest among astronomers, early attempts to detect

The quest for cosmic gamma rays

1900

Paul Villard (École Normale at rue d'Ulm, Paris) discovers that radium emits a form of radiation more penetrating than X-rays.

1903

Ernest Rutherford (McGill University, Montreal) names Villard's discovery "gamma rays."

1949

Enrico Fermi (University of Chicago) publishes the first quantitative ideas on how the galaxy's magnetic fields could accelerate cosmic rays — electrons, positrons, and atomic nuclei moving near the speed of light.

1958

Philip Morrison (Cornell University) introduces the concept of gamma-ray astronomy. He predicts gamma rays from many sources, including supernova explosions and interstellar gas bombarded by cosmic rays.

Early 1960s

NASA's Explorer 11 satellite makes the first reliable detection of cosmic gamma rays, finding 22 photons in 9 hours of data. Efforts using balloon-borne experiments and ground-based Atmospheric Cerenkov Telescopes prove inconclusive.

1967–1969

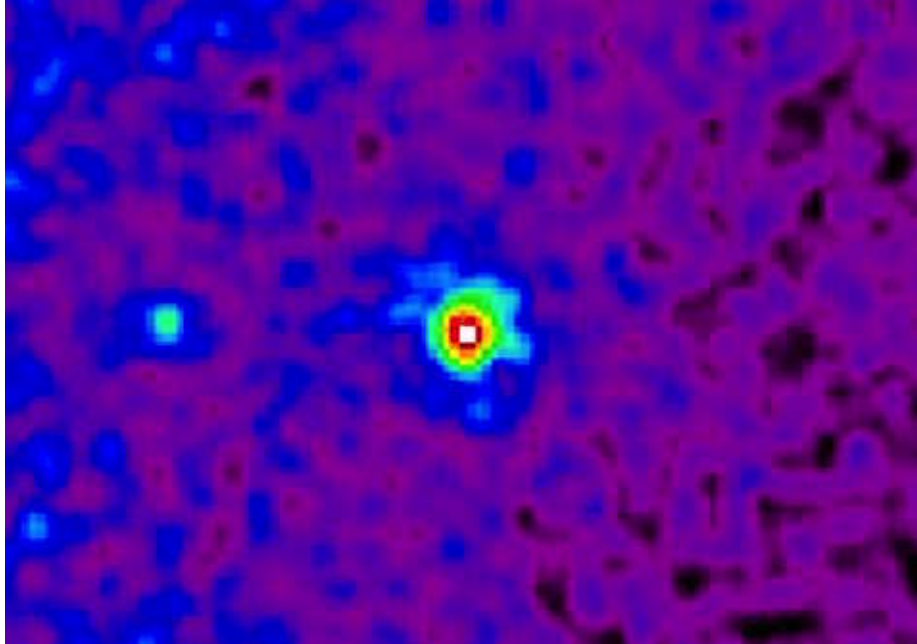
NASA's Orbiting Solar Observatory-3 detects 621 gamma-ray photons from deep space. The mission verifies galactic emission from cosmic-ray interactions and discovers the diffuse gamma-ray background.

Summer 1969

The U.S. Air Force Vela satellites have searched for clandestine nuclear weapons tests for 6 years. Ray Klebasabel (Los Alamos Scientific Laboratory, New Mexico) discovers the first gamma-ray burst while examining Vela 4 data from July 2, 1967. The existence of these events remains classified until 1973.

1972

NASA's Small Astronomy Satellite-2 confirms the diffuse gamma-ray background. The satellite studies the Crab and Vela pulsars and finds an unexpected point source, now identified as the X- and gamma-ray pulsar Geminga.



▲ **High-energy gamma rays** pour from NGC 1275 (center), the core member of the Perseus galaxy cluster. Although Fermi sees plenty of such gamma rays from NGC 1275, NASA's earlier Compton Gamma-Ray Observatory did not. The beam from this galaxy's central black hole strengthened in the decade between these two missions. Brighter colors indicate more gamma rays at energies above 200 MeV.

◀ **NGC 1275 appears** as a hotbed of activity at visible wavelengths. The bright central region in this Hubble image masks a supermassive black hole. Gamma rays emanate from the particle beams created by the black hole.

gamma rays from space proved highly discouraging. Half a century later, Fermi netted 1,500 sources in its first year of operations — a fivefold increase from the best previous efforts. Yet X-ray astronomy, which started in the 1960s, now catalogs hundreds of thousands of sources. Why such a vast difference?

Two reasons: Detecting gamma rays from cosmic sources proved more difficult than scientists expected, and early predictions of the source intensities were much too optimistic. Gamma rays have great penetrating power. They can zip through a few inches of lead, so there's no way to focus them. The aperture of any space-based gamma-ray telescope is simply the size of the detector. To complicate matters, charged particles can masquerade as gamma-ray signals, and orbital sensors pick up far more of them than they do actual gamma rays. Fermi's state-of-the-

art LAT sees only about one gamma-ray photon every 2 minutes from the Vela pulsar — and that's the strongest persistent source of gamma rays in the sky.

Fermi's two instruments — the LAT and the Gamma-ray Burst Monitor (GBM) — mark the zenith of space-based gamma-ray detection. Together, they capture the widest range of gamma-ray energies of any satellite, from 8,000 eV to more than 300 billion eV (GeV). (See "Fermi: Under the hood," page 28.) This gives astronomers their best-ever opportunity to explore the extreme universe.

So, what do they see?

Flaring blazars

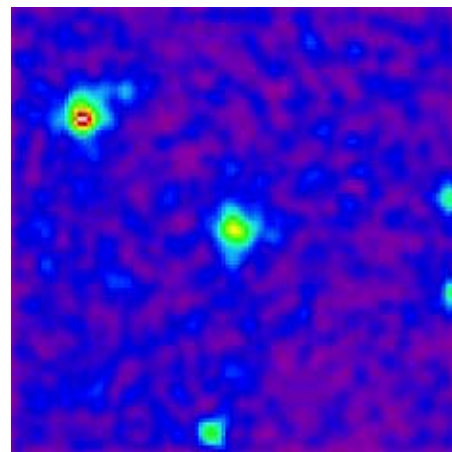
Active galaxies called blazars make up nearly half of the point sources Fermi detected during its first year. Astronomers think each blazar — like its better-known cousin, the quasar — harbors a well-fed black hole that may weigh a billion solar masses or more. As matter falls into this monster, the blazar emits oppositely directed jets of particles traveling near the speed of light. In the case of blazars,

the most luminous class of active galaxy, astronomers suspect we're looking right down one of the jets, whereas we view quasars and other active-galaxy types at larger angles. And emission from blazars can change significantly on timescales of less than an hour to years.

No one understands exactly what's happening in blazars or how the gamma rays arise. "When one of these things goes off, we see it coming, we see it peak, and we see it go away," says Michelson. "Eventually, that will provide us with tremendous insights into the physics of what's generating that emission."

One of the first targets for a multi-wavelength campaign involving Fermi was PKS 2155–304, a blazar located 1.5 billion light-years away in the southern constellation Piscis Austrinus. Typically, it's a faint but detectable gamma-ray source. But when it undergoes an outburst, as it did in 2006, it can become the brightest source in the sky.

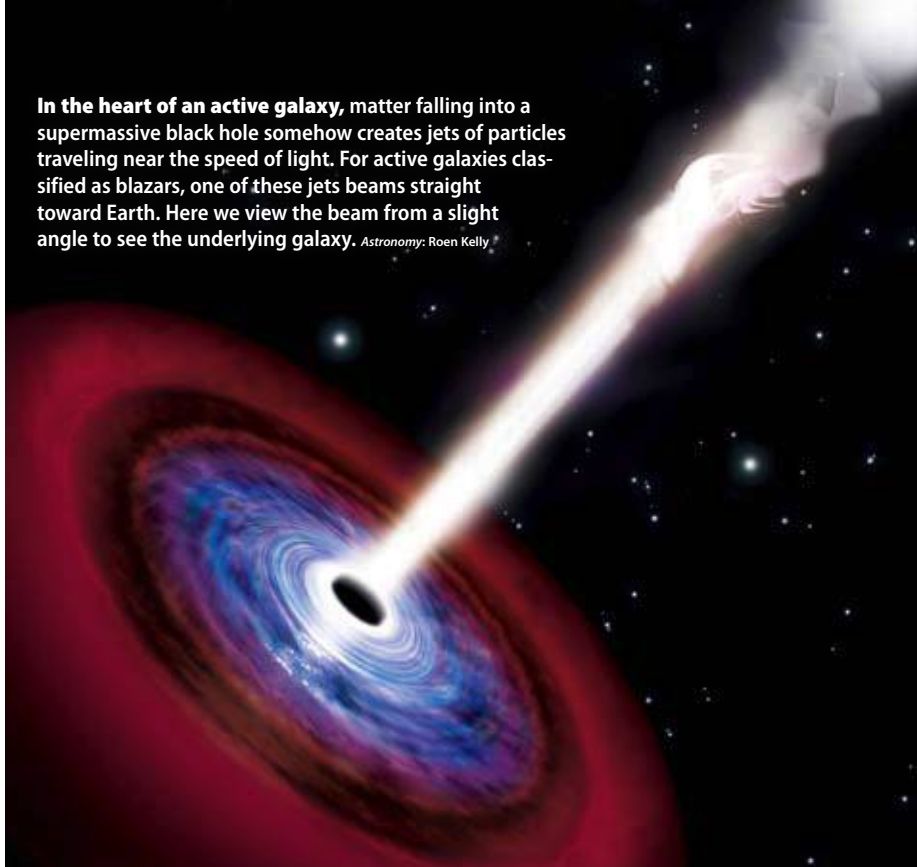
In August and September 2008, Fermi teamed up with the High Energy Stereoscopic System (H.E.S.S.), a ground-based array in Namibia that observes particle cascades created when gamma rays with energies above 100 GeV slam into Earth's atmosphere. The two facilities monitored PKS 2155–304 in its quiet state. During flares of this and other blazars, the X-ray and gamma-ray emissions rise and fall with each other. But when PKS 2155–304 is quiet, the emissions don't change together — and no one knows why.



Seyfert galaxy PMN J0948+0022 (center) lies 5.5 billion light-years from Earth in the constellation Sextans. Gamma rays from this galaxy show that its central black hole drives a fast-moving particle beam. Brighter colors indicate higher numbers of gamma rays at energies above 200 MeV. NASA/DOE/Fermi LAT Collaboration

Francis Reddy works with the Fermi team in his role as the senior science writer for the Astrophysics Science Division of NASA's Goddard Space Flight Center in Greenbelt, Maryland.

In the heart of an active galaxy, matter falling into a supermassive black hole somehow creates jets of particles traveling near the speed of light. For active galaxies classified as blazars, one of these jets beams straight toward Earth. Here we view the beam from a slight angle to see the underlying galaxy. *Astronomy: Roen Kelly*



What's even stranger is that the galaxy's visible light rises and falls with its gamma-ray emission. "It's like watching a blowtorch where the highest temperatures and the lowest temperatures change in step, but the middle temperatures do not," says Berrie Giebels, an astrophysicist at France's École Polytechnique who works with the H.E.S.S. and Fermi LAT teams.

Then there's the curious case of NGC 1275, the massive Seyfert-type active galaxy located at the heart of the Perseus galaxy cluster, about 225 million light-years away. NGC 1275 ranks among the brightest radio sources in the sky.

Fermi clearly detects gamma rays from this galaxy. Yet a gamma-ray detector named EGRET, which flew on NASA's Compton Gamma-Ray Observatory in the 1990s, failed to see them. "Fermi sees this galaxy shining with gamma rays at a flux about 7 times higher than the upper limit of EGRET," says Jun Kataoka at Waseda University in Tokyo. "If NGC 1275 had been this bright when EGRET was operating, it would have been seen."

This change in the galaxy's output suggests that its particle beam was either inactive or much weaker a decade ago. Such changes clue astronomers into the size of the emitting region. "The gamma rays in NGC 1275 must arise from a source no more than 2 light-years across," explains Teddy Cheung of NASA's Goddard Space Flight Center in Greenbelt, Maryland. "That means we're seeing radiation from the heart of the galaxy — near its black hole — as opposed to emission by hot gas throughout the cluster."

A passel of pulsars

Much closer to home, in our own galaxy, Fermi easily detected a class of pulsars unlike any seen previously. A pulsar is the crushed, rapidly spinning, highly magnetized core left behind when a massive star explodes. Astronomers discovered most of the 1,800 cataloged pulsars through their periodic radio emissions. Theorists believe these pulses arise from narrow, lighthouse-like radio beams emanating from the pulsar's magnetic poles.

1975–1981

Europe's COS-B satellite detects the first extragalactic gamma-ray source: the quasar 3C 273. NASA's High-Energy Astrophysics Observatory-3 discovers 511-keV gamma rays from the galactic center. This line arises when electrons and positrons annihilate each other.

1988

Balloon experiments detect the characteristic gamma rays of newly formed radioactive elements produced in Supernova 1987A.

1989

The Whipple 10-meter Telescope on Mount Hopkins, Arizona, leads the second generation of Atmospheric Cerenkov Telescopes. The telescope detects a steady source of gamma rays from the Crab Nebula, now a "standard candle" in the field.

Early 1990s

Atmospheric Cerenkov Telescopes discover high-energy gamma rays emanating from several blazars.

1991–2000

NASA's Compton Gamma-Ray Observatory revolutionizes the field. Its BATSE instrument detects more than 2,700 gamma-ray bursts (GRBs) all over the sky, indicating that they are titanic explosions in distant galaxies, and shows that GRBs occur in two types — long (durations greater than 2 seconds) and short. The EGRET instrument performs the first all-sky survey above 50 MeV, detecting 271 point sources, including six pulsars and 66 active galaxies known as blazars. Yet 170 sources cannot be associated with known objects at other wavelengths.

1997–2003

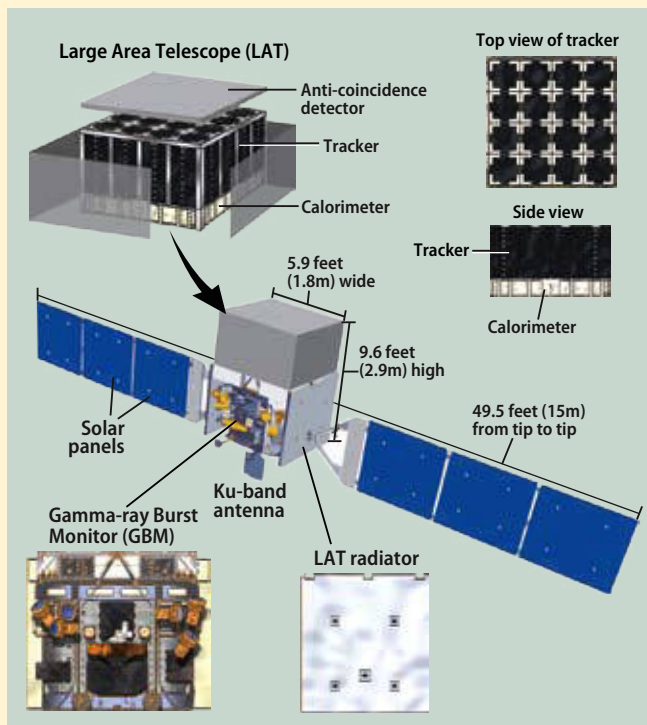
The Italian-Dutch BeppoSAX satellite localizes several long gamma-ray bursts quickly and precisely enough to permit follow-up observations with large ground-based telescopes. These observations prove the bursts occur at extreme distances.

2000–present

A third generation of Atmospheric Cerenkov Telescopes begins work. They include MILAGRO (Los Alamos National Laboratory), the High Energy Stereoscopic System (H.E.S.S., in Namibia), VERITAS (Mount Hopkins, Arizona), CANGAROO (Australia), and MAGIC I and II (Canary Islands).

The four identical telescopes of the High Energy Stereoscopic System in Namibia complement Fermi. They detect faint flashes produced when ultrahigh-energy gamma rays interact with air molecules. *H.E.S.S.*





Fermi's two science instruments, the Large Area Telescope (LAT) and the Gamma-ray Burst Monitor (GBM), sit inside a box 5.9 feet (1.8 meters) wide and 9.6 feet (2.9m) tall. The LAT has four subsystems. The anti-coincidence detector lies on top. It produces flashes of light when a cosmic ray hits it, but not when a gamma ray strikes. Below it sits the tracker, an array of 16 towers that converts an incoming gamma ray into an electron-positron pair, then precisely measures the paths of these subatomic particles.

Below each tracker tower lies a calorimeter, which measures the energies of these particles and, from this, the original gamma-ray's energy. The data acquisition system (not shown) collects data from the other subsystems, weeds out unwanted cosmic rays, and decides what information to send to the ground through the Ku-band antenna.

The LAT radiators (one of which is shown) help keep the LAT cool by radiating heat to space. The GBM lies beneath the LAT and watches for gamma-ray bursts with 14 detectors: 12 designed to capture low-energy gamma rays and two to capture high-energy gamma rays. *Astronomy: Roen Kelly*

Fermi: Under the hood

Fermi is a different kind of telescope. Because no telescope can focus gamma rays, its primary instrument, the Large Area Telescope (LAT), relies on a process called pair production.

When a gamma ray collides with one of the LAT's many layers of tungsten foil, it creates an electron-positron pair. Strips of silicon detectors track the particles as they course through the instrument; reversing this track gives the direction of the original gamma ray. A separate detector absorbs and measures the particle energies.

Unfortunately, another form of high-energy radiation also can penetrate the LAT: cosmic rays. Unlike gamma rays, which are a form of electromagnetic radiation, cosmic rays are fast-moving subatomic particles (mostly protons) that outnumber gamma-ray photons by 100,000 times or more. So the LAT uses another component — called an anti-coincidence detector — to weed out cosmic rays. If the LAT senses an electron-positron pair when the anti-coincidence detector senses nothing, then the signal was probably made by a gamma ray.

The LAT is far more sensitive than previous instruments. "The LAT gains for three reasons: a much wider field of view, a larger effective area, and better angular resolution," explains LAT principal investigator Peter Michelson. The instrument surveys the whole sky every 3 hours (two orbits) and sees gamma rays with energies ranging from 20 MeV to more than 300 GeV.

For energies lower than 10 GeV, the LAT is about 30 times more sensitive than anything flown previously. For energies greater than 100 GeV, there is no effective comparison — it's terra incognita.

The spacecraft's secondary instrument, the Gamma-ray Burst Monitor (GBM), spotted 257 gamma-ray bursts in its first year. These high-energy blasts most likely occur when massive stars die or when orbiting neutron stars spiral together and merge.

"Our job is to identify burst locations well enough to tell the LAT where to look," says Bill Paciesas, who heads the GBM team at NASA's Marshall Space Flight Center in Huntsville, Alabama. "We're also detecting other interesting things, including flares from energetic neutron stars in our own galaxy — and even brief flashes of gamma rays from terrestrial thunderstorms."

The GBM is sensitive to photons ranging from 8,000 eV to 30 MeV. Bursts seen by both the GBM and LAT provide an unprecedented look across a broad gamma-ray spectrum, enabling scientists to peer into the processes at work in these powerful events. — F. R.

Then came Fermi's early observations of a 10,000-year-old supernova remnant named CTA 1, located 4,600 light-years away in Cepheus. About three times every second, something within the remnant sends a surge of gamma rays toward Earth. Fermi had discovered the first pulsar that pulsed only in gamma rays.

"This resolves a long-standing scientific mystery," says Dave Thompson, a Fermi deputy project scientist. "CTA 1 contains an X-ray and gamma-ray source with all indications of being a pulsar, but no pulsations had been found at any wavelength."

A pulsar's radio beams represent only a few parts per million of its total power,

whereas its gamma rays account for 10 percent or more, according to Stanford's Roger Romani. With this new pulsar class, together with Fermi detections of dozens of other pulsars, scientists now see the actual power of these machines.

Blast from the past

One of the most astonishing results from Fermi so far involves gamma-ray bursts (GRBs), the titanic explosions thought to herald the birth of black holes. LAT observations of GRB 080916C, which was a type of burst associated with the death of a massive star, show that the explosion had the fastest jet motions and the highest-energy initial emissions ever

seen to that time. Thanks to rapid follow-up observations from a ground-based group led by Jochen Greiner of the Max Planck Institute for Extraterrestrial Physics in Garching, Germany, astronomers nailed down the burst's distance: 12.2 billion light-years.

Coupled with the Fermi measurements, the distance allows astronomers to determine the slowest speeds possible for the material that emitted the initial gamma rays. Incredibly, bullets of gas in the jets from this explosion must have moved no slower than 99.9999 percent the speed of light.

GRB 080916C's speed record didn't stand long. In May 2009, a burst desig-



In gamma-ray-only pulsars, the gamma rays form far above the object's surface in a broader region than the pulsar's narrow radio beams. Fermi results show that the pulsed gamma rays likely arise in blobs of superheated plasma (purple) trapped in the pulsar's powerful magnetic field. Each time the rapidly spinning pulsar rotates, it sends gamma rays hurtling in our direction. *Astronomy: Roen Kelly*

nated GRB 090510 — a short burst of a type associated with the merger of two neutron stars — exhibited even faster material flows.

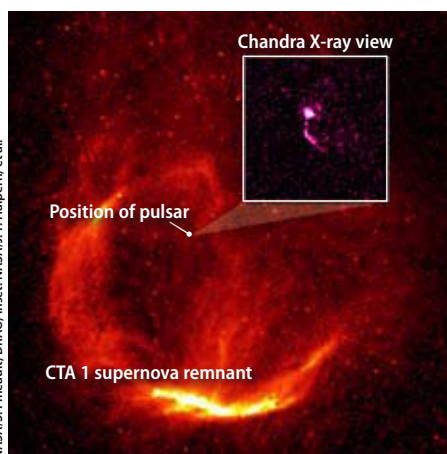
More interestingly, the highest-energy photons from both of these bursts tell scientists something about the frothy, foam-like structure of space predicted by quantum gravity, the so-far elusive theory that would unite quantum mechanics and Einstein's general relativity.

According to current ideas, the frothiness of space retards the arrival of a burst's highest-energy photons more than

it does the lowest-energy photons. The effect is minuscule. "It takes billions of years for these predicted shifts to show up as a delay of a few seconds," says Thompson. In the case of GRB 090510, a single 31 GeV photon shows a lag no greater than 1 second after traveling 7 billion years.

This result rules out any approach to quantum gravity that predicts a strong wavelength-dependent change in the speed of light. Einstein's relativity theory, which posits that the speed of light is a constant, remains standing. But the result eliminates many variations of quantum gravity, including some based on string theory. Still, other approaches that predict more subtle effects remain viable. "Einstein's special relativity is one up," says Peter Mészáros of Pennsylvania State University, "but the game is not over."

The Fermi Gamma-ray Space Telescope mission continues on a fast track. "Fermi has just started on what we hope will be a decade-long tour of the gamma-ray sky, and we're delighted with its successes thus far," says Julie McEnery, the mission's project scientist at Goddard. "But we suspect the greatest science from Fermi will be something no one has even thought of yet." ☾



NASA/S. Pineault, DRAO; inset: NASA/J. F. Halpern, et al.

A new type of pulsar that beams energy only in gamma rays turned up soon after Fermi opened its eye. The first was found in the 10,000-year-old supernova remnant CTA 1, seen here in a radio map. Inset: In 2003, Chandra imaged a kinked jet but detected no pulses issuing from this object.



Watch a gamma-ray pulsar in action at www.Astronomy.com/toc.

2002–present

The European Space Agency's International Gamma-Ray Astrophysics Laboratory (INTEGRAL) satellite provides spectral measurements of low-energy gamma-ray sources.

2004–present

NASA's Swift satellite detects about 100 gamma-ray bursts per year and provides precise positions for rapid studies by other facilities. Follow-up observations of short bursts strongly support the notion that many result from mergers of neutron stars or of neutron stars and black holes.

2007

The Italian gamma-ray satellite AGILE launches April 23. It carries a gamma-ray detector similar in sensitivity to Compton's EGRET instrument, but with a wider field of view.

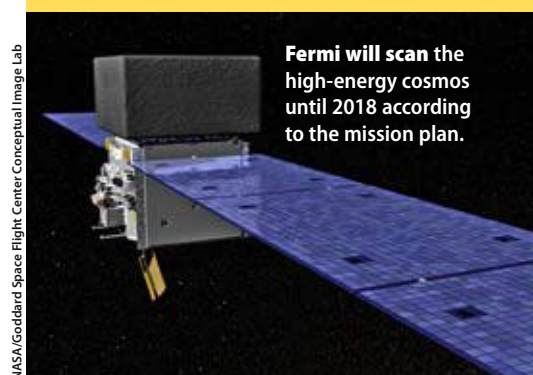
2008

NASA's Fermi Gamma-ray Space Telescope launches. It carries the most sensitive gamma-ray detector ever orbited. Fermi quickly identifies a new class of gamma-ray-only pulsars and observes gamma-ray bursts and flares from active galaxies.

2009

In its first year, Fermi detects 257 gamma-ray bursts (GRBs) and nearly 1,500 objects — including more than 600 blazars and other active galaxies, more than 50 pulsars, eight globular clusters, at least three X-ray binary star systems, and several supernova remnants. But fully half of the sources have no plausible counterpart at other wavelengths.

Fermi also finds more cosmic-ray electrons and positrons with energies above 100 GeV than expected. Fermi places new limits on the mass of hypothetical quantum gravity particles, thanks to the highest-energy photons from GRBs.



Fermi will scan the high-energy cosmos until 2018 according to the mission plan.

NASA/Goddard Space Flight Center Conceptual Image Lab

What we've learned



Saturn's moon Titan has an almost earthlike landscape. The satellite has large dune fields, mountains, lakes of methane and ethane, and a weather cycle. Astronomers have used the Cassini/Huygens mission to map many surprises on Titan. We should probably expect more. *Michael Carroll for Astronomy*

TITAN

about a strange new world

Cassini's 5-year exploration has revealed the saturnian moon's atmosphere, mountains, dunes, rivers, lakes, and seas. And we should expect many more discoveries.

by Michael Carroll

To 16th-century Europeans, the Americas sprawled across freshly charted seas as *terra nova*, or new land. Serpentine coastlines faded in and out, waiting for explorers to fill in the blanks. At the mysterious borders, maritime mapmakers drew sea monsters with the cautionary label “thar be dragons.”

Today's maps of Titan, Saturn's largest moon, share a lot in common with those ancient charts. And

Michael Carroll, a frequent contributor, is a space artist and science writer.

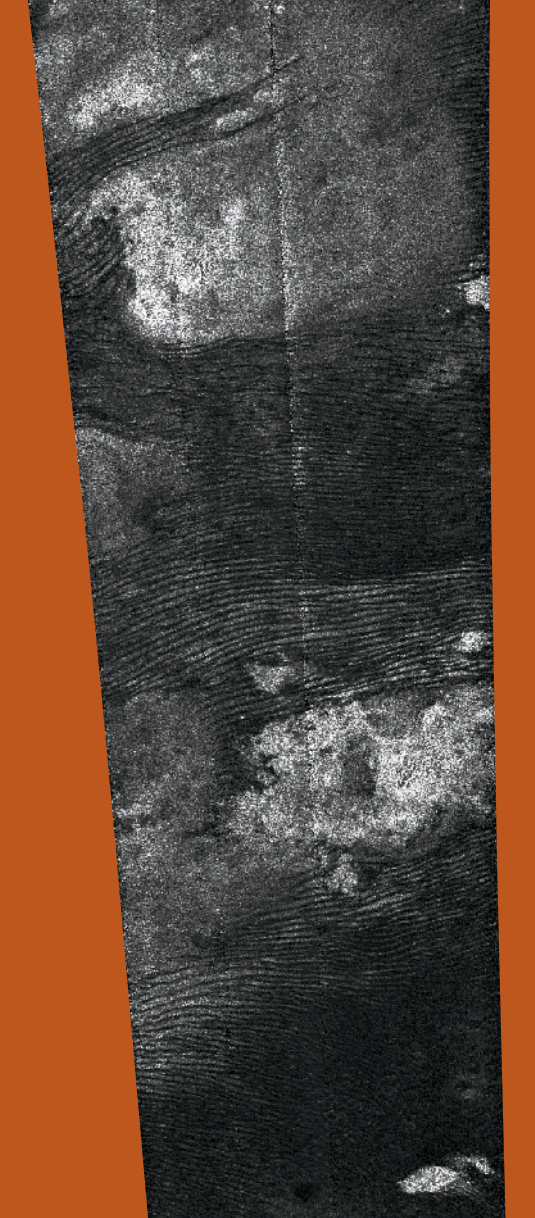
just as ancient maps gave way to AAA travel guides, today's cosmic cartographers are filling in the blanks on their Titan atlases. Titan is — in every sense of the phrase — *terra nova*.

While distance was the major hurdle for terrestrial explorers, it's only one obstacle for planetary researchers. Titan's smoggy atmosphere cloaks its landscape from visible-light instruments. But thanks to Cassini/Huygens — the NASA and European Space Agency Saturn mission — we are seeing Titan's frontiers as never before. Cassini's battery of instruments enables

remote viewing of the surface in the near infrared, as well as detailed imaging using radar. Data from the past 5 years has enhanced and changed our initial concept of the freezing world. Using data from more than 60 close Titan flybys, researchers are focusing on several major areas, including Titan's dunes, atmosphere, mountains, and lakes.

Alien dunes

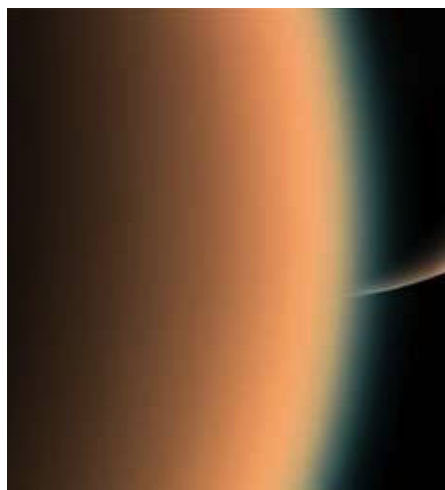
From the mission's start, Cassini's Visual and Infrared Mapping Spectrometer (VIMS) and Imaging Science Subsystem (ISS) instruments revealed dark regions across the face



Dune seas coat regions of Titan. This particular site lies just north of Titan's equator and spans 140 miles by 395 miles (225 km by 636 km). On Earth, dunes tend to form in low-lying areas. The bright patches in the image are likely higher regions that block the formation of dunes. Cassini's radar instrument captured this image. NASA/JPL

of the veiled moon. More detailed radar sweeps revealed that linear sand dunes cover some of those dark areas. During the Cassini mission's first few years, scientists estimated that dunes might cover up to 10 percent of the surface. That ratio has changed, according to Brigham Young University's Jani Radebaugh. "We now estimate that at least 20 percent of Titan's surface is covered by dunes, and perhaps much more." By comparison, dunes cover about 5 percent of Earth's land.

Titan's long dunes act as a sort of weather vane, following the direction of



Titan's hazy limb blocks most of Saturn, which is hiding behind its moon. Astronomers combined red, green, and blue Cassini images to create this natural-color view of Titan's thick atmosphere. NASA/JPL/SSI

the moon's winds. Titan's atmosphere is $1\frac{1}{2}$ times as dense as Earth's at sea level. Chilled to -290° Fahrenheit (-179° Celsius), the sluggish air moves across Titan's face like a planetary tidal wave. The shape and orientation of the dunes indicate the winds blow from west to east. In February 2009, researchers mapped 16,000 dune fields on the moon to confirm the findings.

Titan's dunes may be one of the most alien features of the satellite. The largest dune "sea," known as Belet, stretches some 1,860 miles (3,000 kilometers). Its dunes tower 490 feet (150 meters) high. Unlike the silica sands of Earth, Titan's dunes may consist of pulverized ice or organic material that falls from the sky. Recent research favors the latter, says Radebaugh. "VIMS sees all the dunes as dark. If they were water ice, they should be bright."

Cassini's radar offers another clue. "Not only does radar build up a picture, but we also get information about how the material behaves," she explains. Radar waves that bounce off the surface measure a "dielectric constant," information that tells scientists about the material's size and makeup. Titan's dunes yield a dielectric constant that is inconsistent with water

but mimics fine-grained organic material. This soot-like matter precipitates out of the sky as a result of the interaction between the Sun's ultraviolet radiation and methane in Titan's atmosphere.

Dunes need sufficient winds and sediments to form. They also need fairly dry conditions. Even so, on Earth coastal dunes snake along shores of lakes and oceans. Astronomers haven't found such dunes on Saturn's moon, says Radebaugh. "That's a really interesting thing we need to puzzle through. There are no dunes above 60° latitude." Radebaugh suggests that the lack of dunes in polar regions, where researchers have found evidence of methane lakes, may be the result of elevated levels of methane vapor.

Atmosphere

How Titan's dunes form and move depends on the dynamics of the moon's dense atmosphere. Before Cassini, many researchers proposed simple atmospheric models for Titan. But Cassini has revealed a world of complexity above the landscape. While the majority of Titan's atmosphere is nitrogen, its second-most abundant constituent, methane, is the driving force behind chemistry and weather. Because sunlight destroys methane, the gas should be short-lived in Titan's environment. But the atmosphere contains a lot of methane. Something must be replenishing it.

Jonathan Lunine of the University of Arizona's Lunar and Planetary Laboratory has been studying Titan's evolution in an attempt to unravel why Titan has so much methane. Lunine and his team believe Titan's interior pumped methane into its skies during three developmental epochs.

In its formative years, as the moon accreted from the solar nebula, a rocky core formed beneath a water mantle. A water-ice crust topped the mantle. During its first several hundred million years, heat from the moon's formation combined with the warmth of radioactive elements in the core to melt through the crust, thus releasing methane.



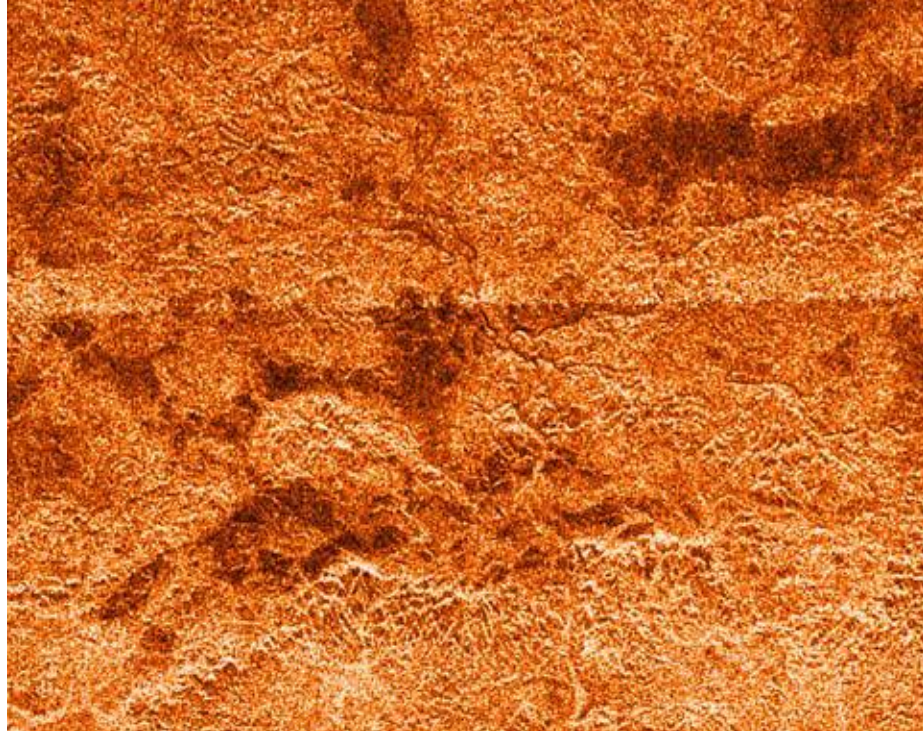
The second release probably occurred about 2 billion years ago, when convection began in Titan's silicate core. This geological burst of heat again melted the crust, which caused methane outgassing. Ammonia that mixed with the water ice would have helped serve as an antifreeze.

The most recent epoch left Titan with a methane-rich atmosphere. "In that last stage, somewhere between half a billion and a billion years ago, the cooling of Titan gets to the point where a layer of [water] ice forms immediately beneath what has been a methane/clathrate crust [methane trapped within a lattice of water ice]," says Lunine. "The cooling crust thickens, and convection begins in that ice crust itself. Upwelling plumes of solid material force the release of methane from the clathrate above it." Lunine adds, "Thermal conditions changed so that, plausibly, you might have geysers or places where methane is leaking out of the ground."

Mountains

If methane is escaping from the interior, it may leave signs of its activity as geysers or volcanic vents. But is there evidence for such eruptions? Rosaly Lopes of NASA's Jet Propulsion Laboratory thinks so. She has been studying several features that resemble volcanoes, including an area called Hotei Arcus, which is part of Hotei Regio. Between October 2005 and March 2006, Cassini flew by Hotei Arcus 3 times.

"VIMS sees brightness changes in two regions, Hotei Regio and western Xanadu, where RADAR sees flow morphology consistent with cryovolcanic flows [super-cold volcanic activity]," Lopes says. She and others believe the VIMS images from those flybys show surface-darkening from one encounter to the next. One likely reason could be cryovolcanism.



Titan's Xanadu region is covered in complex terrain, from mountains (at the bottom of the image) to drainage channels. Cassini's radar mapper captured this view, which spans about 124 miles (200 km) on each side. NASA/JPL

Hotei has also been under scrutiny by Randall Kirk of the U.S. Geological Survey in Flagstaff, Arizona. Kirk is skeptical about the VIMS data, but he still feels Hotei is likely a volcanic flow feature. "The first look we had in radar showed the kind of lobes and protrusions and indentations that you get with lava flows or other viscous material," Kirk says. "Some thought these might be sedimentary deposits related to the narrow channels that were flowing into the area." Then, Kirk's team got a second radar pass, enabling them to construct stereo images of the area. "What we found is that they have a measurable thickness of 100 to 200 meters [330 to 660 feet]; the channels come into the base level."

The new data suggest that the channels could not have deposited the flows, which tower above the surrounding land-

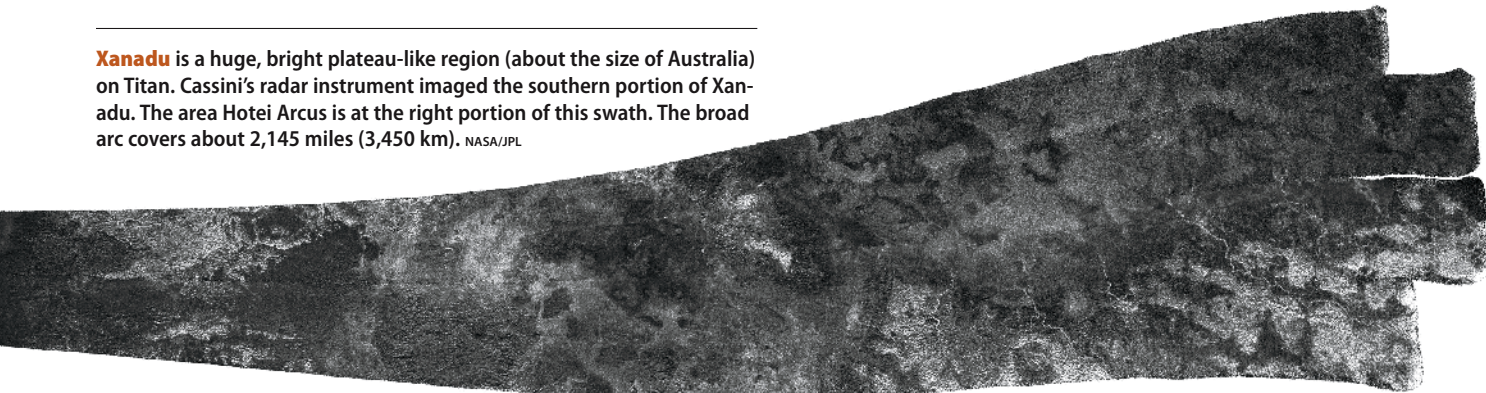
scape. Kirk believes other sites display possible cryovolcanic signatures. "A couple features seem to have a hole in the ground like a caldera [volcanic crater] with a thick, snakey flow coming out of it, similar to silicate lava flows."

Another region, Tui Regio, has the same distinctive spectra that Hotei does and seems to be composed of similar flow-like features. "Some are very enigmatic," says Kirk. "They look like something flowed across the surface, but it's so diffuse that it could be thin or thick; it could be volcanic or it could be outwash."

Whether these structures are volcanic remains to be seen. Skeptics allege Hotei and other suggested volcanic sites may instead be products of uplift or other mountain-building processes.

Titan does display other types of mountains, which are equally baffling.

Xanadu is a huge, bright plateau-like region (about the size of Australia) on Titan. Cassini's radar instrument imaged the southern portion of Xanadu. The area Hotei Arcus is at the right portion of this swath. The broad arc covers about 2,145 miles (3,450 km). NASA/JPL





Cassini took this radar image as it flew by Titan's south pole. This view shows plentiful evidence for flowing liquids on the moon's surface — river channels have cut through the terrain. The image covers an area 170 miles by 385 miles (270 km by 620 km). NASA/JPL

To many, Titan's summits came as a surprise. Craters dominate the only two other moons of similar size, Jupiter's Callisto and Ganymede. Ganymede also shows grooved terrain. Scientists predicted any mountains on Titan would be remnants of impact crater rims or central peaks. But Cassini has revealed parallel ridges, solitary raised structures, and mountain chains. Geologists offer four possibilities for the origin of these mountains:

1. Compression: As two areas of crust pushed together, the mountains were thrust up from below.

2. Extension: Two sections of crust separated; one remained while the other dropped and formed a "graben," a ridge left along sunken terrain.

3. Mountains are remnants of blocks of material ejected from large impact craters.

4. Erosion stripped away a preexisting plain, leaving mesas.

Some or all of these processes may be at work, says Radebaugh. "It depends on where you are looking. There are long chains ... that are parallel and trend east/west. We're leaning toward compressional formation for those." But other mountains may be products of impact ejecta. Several mountains are oriented radially 120 miles (200 km) from crater Sinlap's center. Calculations show that in Titan's thick atmosphere and low gravity, blocks of material may be thrown from an impact in a relatively preserved state.

Rugged mountains in Titan's far south and in the region called Xanadu appear eroded by river action. River valleys that seem to have carried material fan out across the plains and transect Xanadu. Kirk points to "whole canyon systems eaten into flat-topped plateaus, like the [American] desert Southwest ... very much like Bryce Canyon."

The icy mountains on Titan have gentle slopes with low profiles. Elevations range from 390 feet (120m) to just over 3,280 feet (1,000m). The consistent altitudes are mystifying: Why would all the

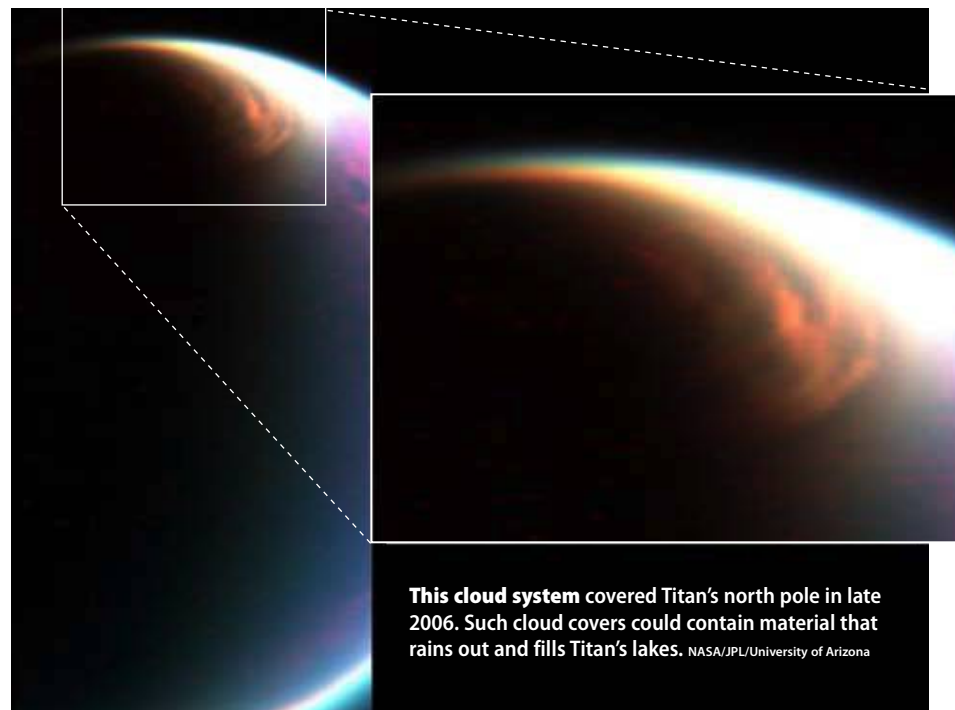
peaks be so similar in height? It may be that the mountains are all ancient and heavily eroded. They may overlie a warmer layer of ice that cannot support a structure above a certain height. Their erosional rates may vary with impurities in the water ice that makes up Titan's surface. Researchers need more detailed imaging to find out if all the mountains are ancient structures, or if they are in various stages of formation, controlled by an as yet undetermined cause.

Titan's summits do not resemble the wrinkle ridges on other worlds. They also differ from the mountain belts on Venus, which seem to be folds in the surface. They do, however, resemble earthly mountains eroded by liquid water. In southern areas, channels cut through terrain at different rates. Some scour the surface while others incise canyons with steeper sides. The variation may be due to differences in surface materials.

Lakes and rivers and rain

Titan's river channels can be deceiving: Despite active methane cloud systems and carved flood plains, researchers believe methane rain falls less often on Titan than water rain falls on Earth.

"There's a way to resolve this paradox," Lunine says. "Particularly in the equatorial regions, Titan is very much a desert planet where rainfall is extremely rare [compared to Earth]. Where you do get

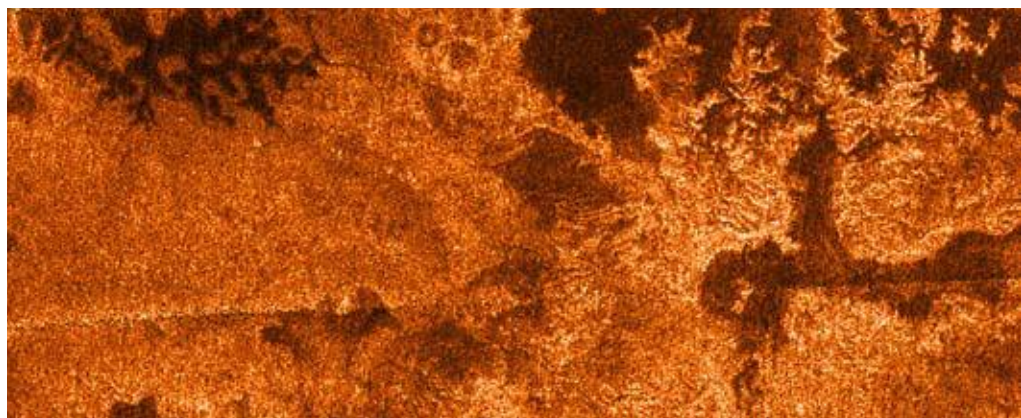


This cloud system covered Titan's north pole in late 2006. Such cloud covers could contain material that rains out and fills Titan's lakes. NASA/JPL/University of Arizona

rain, it's torrential rainfall. The question is: Is that torrential rainfall a seasonal phenomenon or is it long term? Although the methane humidity at the Huygens site was 45 percent, which would be enough to trigger rainstorms on Earth, the solar [heating at Titan] is just too weak to lift moist parcels of air and generate those storms today. You need higher humidity to get a substantial cloud system going. It looks like the equatorial region is just too dry."

This leaves the mystery of how the liquid methane got to the equatorial regions in the first place. Two mechanisms might increase methane humidity at the equator. Methane may migrate from the polar lakes or from subsurface aquifers. With the small amount of sunlight available, getting that atmosphere moist again can take hundreds or even thousands of years. A second possibility is that methane may be tied to a long-term wobble in Titan's axis, which is slaved to that of Saturn.

Earth has similar phenomena, known as the Milankovitch cycles. The shift in Earth's axial tilt, eccentricity, and precession set up long-term trends for climate change. Because of the dynamics of Saturn's orbit, Titan's seasons essentially reverse every 50,000 years. Today, the southern hemisphere has the most extreme summer, but in 50 millennia the north will endure the worst of it. Lunine believes this seasonal oscillation could produce, at times, a more humid equator. "The bottom line is that I don't think those torrential rainstorms at the equator are seasonal," he says. "I think they occur



Lakes abound on Titan, and they're filled with liquid methane and ethane instead of water. (Lakes appear as dark regions in this radar image.) The scene covers an area about 190 miles by 60 miles (310 km by 100 km). NASA/JPL

on a longer duration periodicity." A surprising development came to light in 2008 when storm clouds formed over the equatorial regions and spread to the south. This phenomenon may be rare, but Titan showed us that, nevertheless, it does happen.

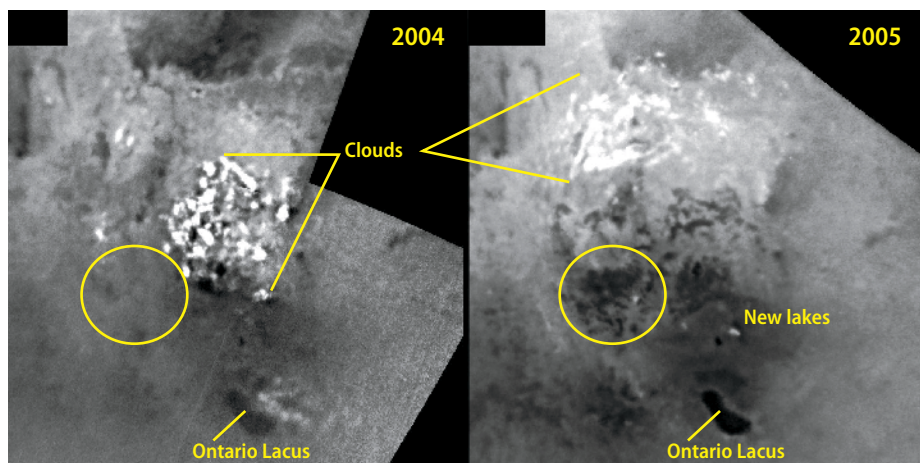
Titan is the only world in our solar system other than Earth with an active liquid cycle involving rain fed by evaporation from surface lakes and rivers. Its rivers drain into liquid-filled basins, some as large as the Great Lakes of North America. Scientists have postulated liquid methane or ethane on Titan's surface since the late 1960s, says Lunine. "We've swung back and forth with Titan. After Voyager, the idea of a global ocean was very appealing. Then the remote sensing data and the early Cassini data seemed to suggest that no, it looked rather dry."

That view morphed in 2007 as Cassini began polar passes, revealing open bodies

of ethane and methane. In Titan's equatorial regions, rare cloudbursts wash over a sort of dune world. In the polar regions, it is a world where it may rain seasonally, and where methane is a prime ingredient for the climate, both in liquid and gaseous form. "It's a different kind of climate from that of Earth; very different from Mars or Venus," Lunine says. "It's a little bit like what Earth might be like in the far future as the Sun gets brighter and drives the oceans off. We'll have equatorial dunes, and whatever water is left will be confined to the poles."

The Cassini mission is in an extended tour, called Equinox, which runs until September 2010. Mission planners hope to get funding for another extension. A "Solstice Mission" could give observers another 7 years of observations, through 2017. The mission's 100 plus Titan-passes would enable scientists to observe Titan for nearly a full set of seasons. Astronomers should learn even more about Titan, and fill in their maps further, from comparing observations of the different seasons.

Distant lands have always captivated humanity. Scientists are replacing Titan's "thar be dragons" with names like Kalseru, Antillia, and Shangri-la. If James Cook or Leif Eriksson were alive today, the adventurers might well set their sites not on the desert wastelands of Mars or the simmering plains of Venus, but on the ocean-bejeweled lands of Titan. Thanks to Cassini/Huygens, we have begun to set sail on those alien seas. ☛



Storm clouds over Titan's south polar region filled new lakes with rain. Cassini's Imaging Science Subsystem captured these views about 1 year apart. They show dark areas — corresponding to lakes — where there weren't any prior to the storm clouds. NASA/JPL/SSI



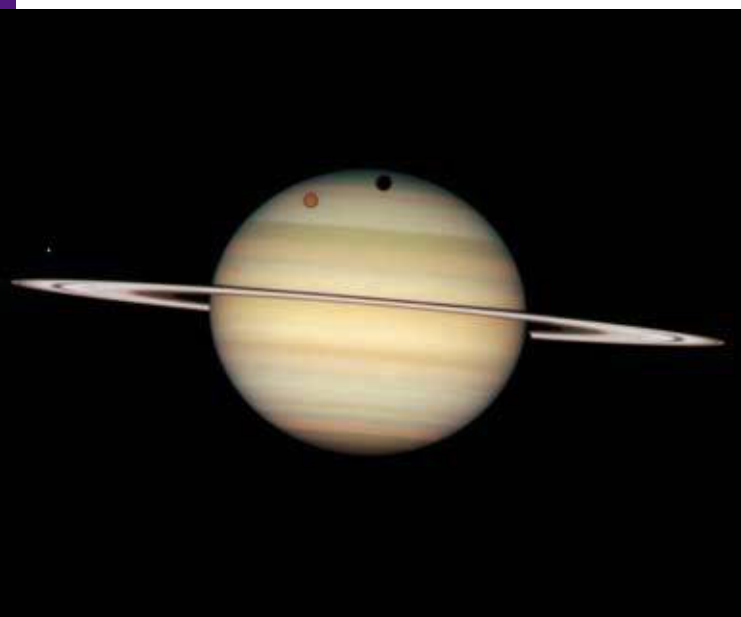
Visit www.Astronomy.com/toc to read more about Titan-Earth similarities.

The Sky this Month

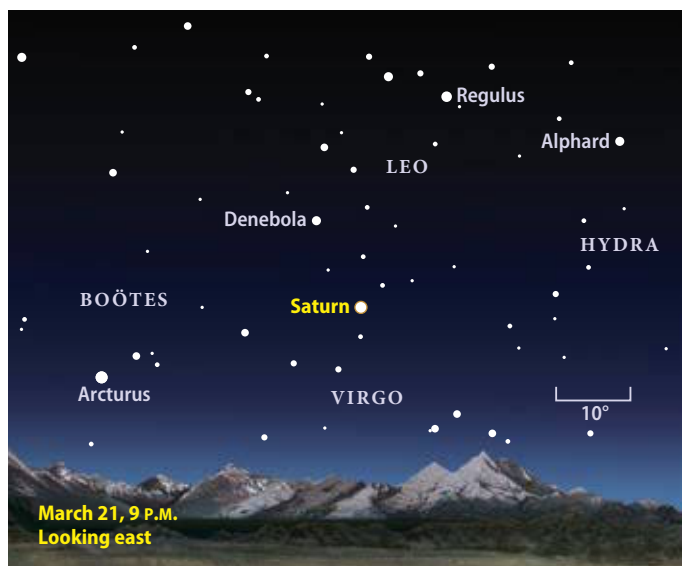
Martin Ratcliffe and Alister Ling describe the solar system's changing landscape as it appears in Earth's sky.

March 2010

Saturn's rings reappear



Saturn's rings tilt 3° to our line of sight at this month's opposition, slightly more than in this Hubble Space Telescope view from February 2009. Notice orange Titan and its black shadow crossing Saturn's north polar region. NASA/ESA/Hubble Heritage Team (STScI/AURA)



The ringed planet reaches peak visibility the night of March 21/22, when it lies opposite the Sun in our sky and remains visible all night. You can find it climbing in the east after darkness falls. Astronomy: Roen Kelly

The March skies open with a spectacularly bright Venus hugging the western horizon just after sunset. Late in the month, Mercury joins Venus in the evening twilight. Mars rides high in the southeast as darkness falls. Although it is now past its best, the Red Planet remains an attractive sight with naked eyes and a worthwhile target for those with medium-sized scopes.

But the best is yet to come: Saturn reaches opposition March 21. The ringed planet then rises in the east at sunset, appears highest in the south at local midnight, and sets as dawn breaks. At opposition, Saturn appears at its biggest and brightest for the year.

Let's begin our tour of the early spring sky where we normally do, in the west shortly after the Sun goes down. Here, **Venus** dazzles at magnitude -3.9 . The brilliant planet climbs slowly higher with each passing night. On March 1, it lies 4° above the horizon 30 minutes after sunset and sets a half-hour later. By month's end, it appears 12° high 30 minutes after sunset and doesn't dip below the horizon for another hour.

Venus' appearance through a telescope hardly changes during March. Its diameter remains 10" all month while its phase wanes almost imperceptibly, from 98 percent to 95 percent lit. By late summer,

36	Saturn shines big and bright	  
41	Meteor watch	
41	Rising Moon	
42	When to view the planets	  
42	Saturn's parade of moons	
42	Comet search	
43	Locating asteroids	 
43	Jupiter returns before dawn	  
	Visible to the naked eye	
	Visible with binoculars	
	Visible with a telescope	

Venus will grow dramatically larger and its gibbous phase will diminish to a crescent.

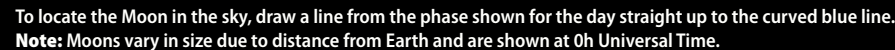
The highlight of Venus' month arrives March 16. That evening, a slender crescent Moon hovers 7° to the planet's right. Binoculars will provide the best views of this pretty conjunction by pulling these objects out of the twilight.

The **Moon** grows more conspicuous with each passing day. In early spring, the ecliptic — the apparent path of the Sun across the sky (which the Moon and planets follow closely) — makes a steep angle to the western horizon after sunset. So, as the Moon pulls farther from the Sun each evening, it climbs significantly higher.

— Continued on page 41

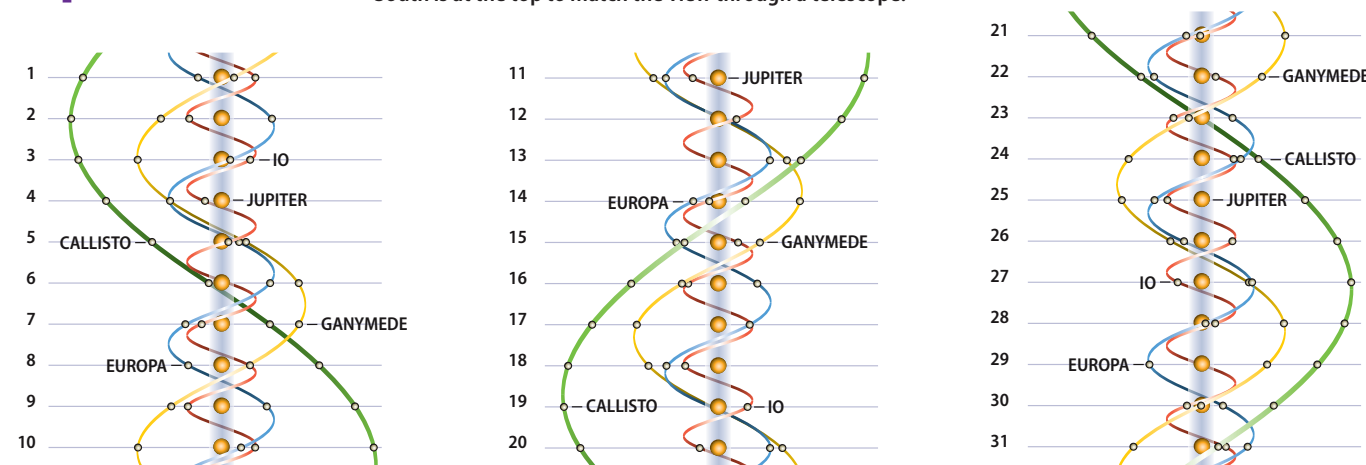


Early evening

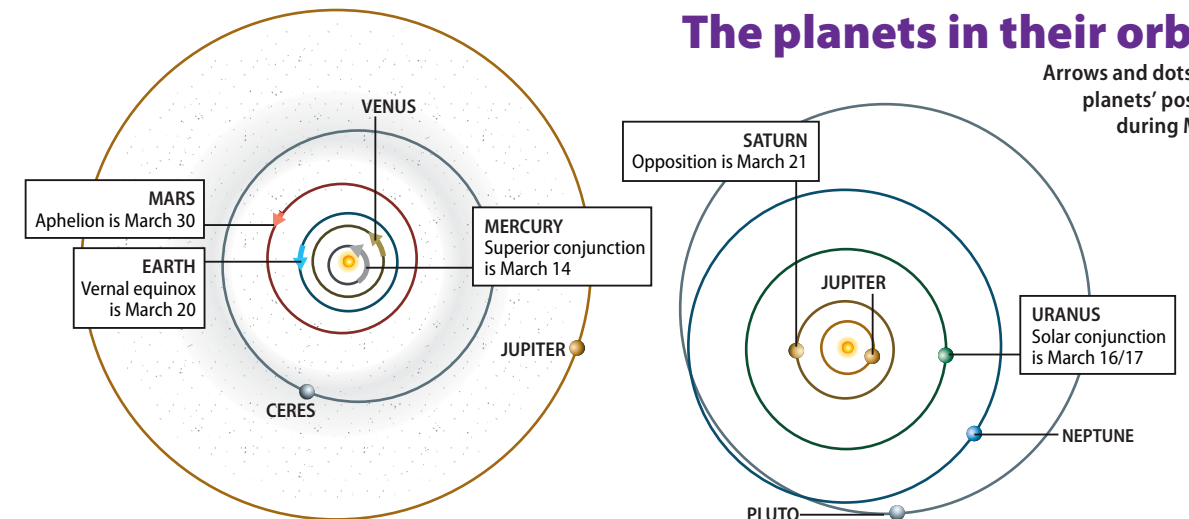


PLANETS									
Date	March 31	March 15	March 15	March 15	March 15	March 15	March 15	March 15	March 15
Magnitude	-1.0	-3.9	-0.2	8.7	-2.0	0.5	5.9	8.0	14.0
Angular size	6.1"	10.2"	10.7"	0.5"	33.1"	19.5"	3.3"	2.2"	0.1"
Illumination	74%	97%	94%	97%	100%	100%	100%	100%	100%
Distance (AU) from Earth	1.110	1.637	0.873	2.663	5.959	8.511	21.089	30.904	31.975
Distance (AU) from Sun	0.308	0.724	1.665	2.766	4.987	9.497	20.096	30.022	31.801
Right ascension (2000.0)	1h33.4m	0h35.4m	8h13.0m	17h55.0m	22h59.2m	12h10.3m	23h47.6m	21h57.7m	18h21.5m
Declination (2000.0)	11°04'	2°37'	23°30'	-21°01'	-7°31'	1°41'	-2°08'	-12°54'	-18°14'

Dots display positions of Galilean satellites at 6 A.M. EDT on the date shown. South is at the top to match the view through a telescope.

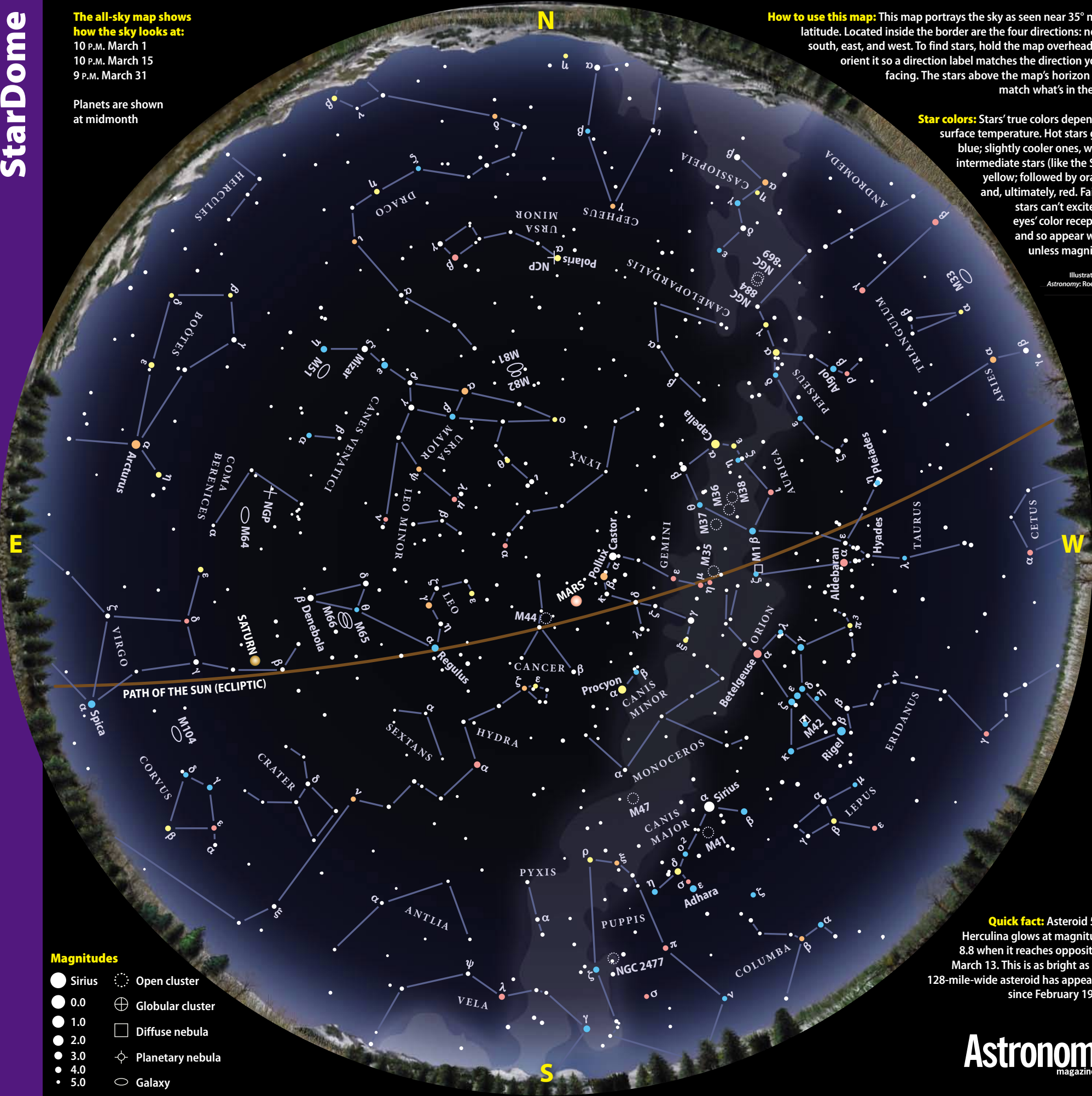


Arrows and dots show planets' positions during March.



The all-sky map shows how the sky looks at:
10 P.M. March 1
10 P.M. March 15
9 P.M. March 31

Planets are shown at midmonth



How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

Star colors: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white unless magnified.

Illustrations by Astronomy: Roen Kelly

- Magnitudes**
- Sirius
 - 0.0
 - 1.0
 - 2.0
 - 3.0
 - 4.0
 - 5.0
 - Open cluster
 - ⊕ Globular cluster
 - Diffuse nebula
 - ⊛ Planetary nebula
 - Galaxy

Quick fact: Asteroid 532 Herculina glows at magnitude 8.8 when it reaches opposition March 13. This is as bright as the 128-mile-wide asteroid has appeared since February 1996.

March 2010

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.

Calendar of events

- 2 The Moon passes 8° south of Saturn, 5 A.M. EST
- 7 Last Quarter Moon occurs at 10:42 A.M. EST
- 11 Mars is stationary, 4 A.M. EST
- 12 The Moon is at apogee (252,282 miles from Earth), 5:05 A.M. EST
- 13 The Moon passes 4° north of Neptune, 11 A.M. EST
- Asteroid Herculina is at opposition, 11 A.M. EST
- 14 Mercury is in superior conjunction, 9 A.M. EDT
- 15 New Moon occurs at 5:01 P.M. EDT
- 17 Uranus is in conjunction with the Sun, 3 A.M. EDT
- The Moon passes 7° north of Venus, 8 A.M. EDT
- 20 Vernal equinox occurs at 1:32 P.M. EDT

21 Saturn is at opposition, 9 P.M. EDT

Special observing date

21 Saturn's rings tilt 3.2° to our line of sight at opposition, a significant increase over last year's more edge-on appearance.

- 23 First Quarter Moon occurs at 7:00 A.M. EDT
- 24 Asteroid Pallas is stationary, 11 P.M. EDT
- 25 The Moon passes 5° south of Mars, 10 A.M. EDT
- 28 The Moon is at perigee (224,859 miles from Earth), 12:59 A.M. EDT
- 29 The Moon passes 8° south of Saturn, 2 P.M. EDT
- Full Moon occurs at 10:25 P.M. EDT
- 30 Mars is at aphelion (154.9 million miles from the Sun), 7 P.M. EDT

See tonight's sky in Astronomy.com's

— Continued from page 36

When it's near Venus March 16, the Moon lies 6° high 30 minutes after sunset. It then shows the smallest of crescents, appearing barely 1 percent lit. One night later, the Moon appears 17° high and sports a 4-percent-lit crescent. On the next night, our celestial neighbor has climbed 28° above the horizon and appears 9 percent illuminated. And by the 19th, it's already climbed 40° high a half-hour after sunset, but remains a thin crescent, just 16 percent lit.

The Moon's most impressive appearance comes one night later, on March 20. After darkness falls in North America, you will find the Moon crossing the southern reaches of the Pleiades star cluster (M45). The most striking views of this conjunction

Martin Ratcliffe provides professional planetarium development for Sky-Skan Inc. in Nashua, New Hampshire. Meteorologist **Alister Ling** works for Environment Canada in Edmonton, Alberta.

Rising Moon

Climb every (lunar) mountain

The half-lit First Quarter Moon is a detail-packed world of dramatic contrasts. Take a look the evening of March 22 or 23, and you'll find a grand mountain range straddling the middle of the Moon's disk slightly north of the equator. The lunar Apennines appear rugged compared with the smoother lava plains to their east.

The mountains cast long shadows as the Sun rises over them, telling astronomers that they thrust upward some 3 miles. If you spot a spiky shadow, watch it shorten during an hour's observation.

As it curves gently to the northeast, the spine of the Apennines turns into the Caucasus Mountains. Observers 100 years ago would have been shocked to learn that these mountain ranges are but a small section marking the edge of a vast basin some 750 miles across. This impact feature, known as Mare Imbrium, formed when a large asteroid slammed into the young Moon.

It took more than 3 decades to go from Galileo's initial observations of the Moon to printed charts good enough to be useful today. For mapmaker Johannes Hevelius, the appearance of lunar mountains reminded him of Europe's great ranges. The earthly Apennines form the backbone of Italy. But of the nearly 300 features Hevelius named, only 10 remain on maps today, all of them mountains or ranges.

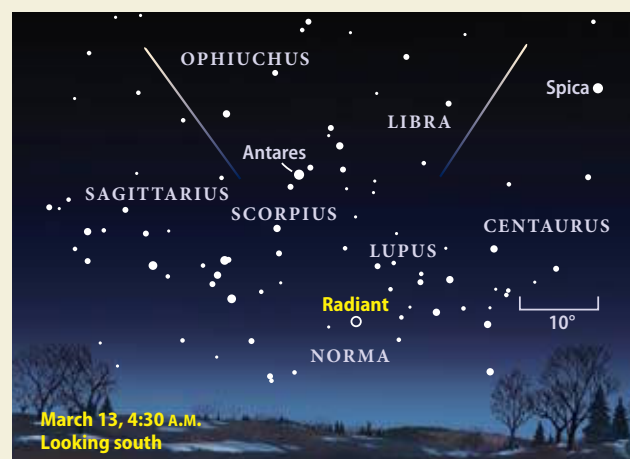
will come through binoculars. A telescope won't show the cluster in all its glory, but it will let you follow the Moon as it blocks the light from a few of the stars.

The ecliptic's steep angle to the horizon also helps **Mercury** appear unusually high during its evening apparition. The innermost planet climbs out of the solar glow to meet Venus during the month's final week. You might try to spot Mercury as early as March 22. Just 20 minutes after sunset and still in a bright sky, Mercury then lies 3° high and 9° below Venus. Any significant haze will mask the innermost planet.

Mercury climbs higher through the end of March. On the 31st, it lies 3° from Venus in the evening twilight. They stand 10° high 30 minutes after sunset and remain visible until about 8:30 p.m. local daylight time. This is a prelude to Mercury's best evening appearance of 2010. It will reach its peak altitude near the end of April's first week.

Although **Mars** reached opposition and best visibility

Meteor watch



March 13, 4:30 A.M.
Looking south

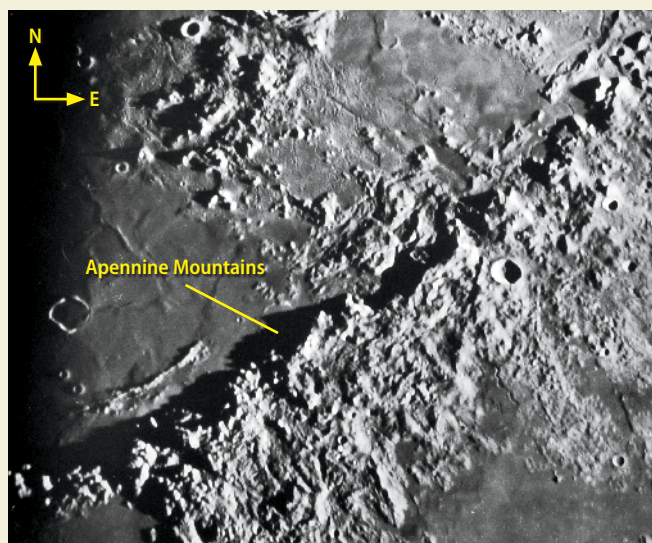
Gamma Normid meteors peak before dawn March 13. Although this minor shower produces only a few meteors per hour, the Moon doesn't interfere with the view this year. *Astronomy: Roen Kelly*

Head south to see a few long trails

Although no major meteor showers occur in March, it pays to keep your eyes peeled for the occasional sporadic meteor. Under a clear dark sky, you'll typically see 5 or so sporadics per hour.

If you live in the southern United States or farther south, you might notice a slight enhancement in the meteor rate before dawn March 13. That's when the minor shower known as the Gamma Normids peaks. This shower produces only 4 meteors per hour at best, and that's when the radiant (the point from which the meteors appear to come) lies overhead.

The Gamma Normid radiant lies in the southern constellation Norma, which barely pokes above the horizon before dawn breaks. Still, meteors that come from low radiants tend to produce long streaks, so it won't hurt to look. The waning crescent Moon rises during twilight and won't interfere.



The lunar Apennine Mountains stand out around First Quarter Moon. Look for their long shadows reaching onto the eastern shores of Mare Imbrium March 22 and 23. *Consolidated Lunar Atlas/UA/LPL*

When to view the planets

EVENING SKY

Mercury (west)
Venus (west)
Mars (southeast)
Saturn (east)

MIDNIGHT

Mars (west)
Saturn (southeast)

MORNING SKY

Jupiter (east)
Saturn (west)

in late January, it remains conspicuous throughout March. The Red Planet lies in Cancer the Crab, which places it high in the southeast after darkness falls. And on March 1, Mars shines at magnitude -0.6 , brighter than any star except Sirius. The planet fades by half during March, dimming to a still-bright magnitude 0.1 by month's end.

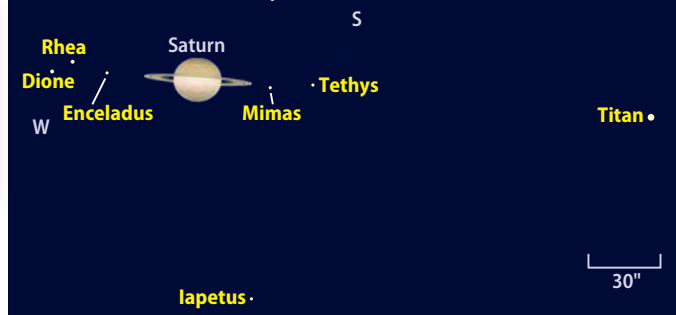
Mars doesn't change position much relative to the background stars. Its westward motion, which started late last year, comes to a halt March 11. It then starts to move eastward slowly. The planet will pass just north of the Beehive star cluster (M44) in mid-April.

In early March, Mars presents a disk spanning $12''$.

That's still large enough to show detail through most telescopes. But the retreating planet shrinks to $9''$ in diameter by month's end. Although Mars' gibbous phase grows more noticeable as March progresses, you'll need a telescope with an aperture of at least 10 inches to resolve many surface features on a disk that small.

The best time to observe Mars through a telescope is in midevening, when the planet stands high in the south. Viewers in North America will see the following features near the center of the planet's Earth-facing hemisphere: on March 1, the broad desert regions, which includes the Tharsis Ridge; March 8, Solis Lacus; March 15, Mare Acidalius; March 22, Arabia; and March 29, Syrtis Major.

Saturn on March 9, 11:30 P.M. EST



To see Saturn's brightest moons, look the night of March 9/10. Inner satellites Mimas and Enceladus then lie their farthest from the planet, while distant Iapetus passes its closest. *Astronomy: Roen Kelly*

Mars takes a bit more than a half-hour longer to rotate on its axis than Earth. So, the Red Planet's disk appears to rotate backward by 9° from one evening to the next. You can view the entire disk by observing during evenings throughout March, or simply watching over the course of the night a few times during the month.

Minor planet **Vesta** reached opposition in February. The brightest asteroid then lay close to the 2nd-magnitude star Algieba (Gamma [γ] Leonis) in Leo the Lion. Vesta remains an

easy binocular object in the same field as Algieba during most of March. On the 1st, it lies 3° west-northwest of Algieba and shines at magnitude 6.2. As March progresses, it slowly pulls away from this star and heads toward 3rd-magnitude Epsilon (ϵ) Leonis, the star at the tip of Leo's Sickle asterism. It lies 1° south-southeast of Epsilon at month's end, when it glows at magnitude 6.8.

On March 1, **Saturn** crosses the sky with a nearly Full Moon. The pair rises before 8 P.M. local time, or

Comet search

Masqueraders at a Messier Marathon

March is the prime time for observers to attempt a Messier Marathon — spotting as many Messier objects as possible in a single night. Many stargazers will try their luck at a marathon during the New Moon weekend of March 13 and 14.

But a surprise awaits deep-sky observers who don't plan ahead. The 10th-magnitude comet C/2007 Q3 (Siding Spring) passes just 2° from the lenticular galaxy M102 (NGC 5866) that weekend. (Although many observers consider M102 a mistaken repetition of M101.)

Can you tell just by looking which is the comet and which is the galaxy? If they appear similar at low power, magnify them. Symmetry is a hallmark of most galaxies. But comets typically have one well-defined edge (which points toward the Sun) caused by the solar wind's interaction with the comet's gas. It also displays a soft-looking side where dust and gas flow away.

Regular Messier marathoners recommend taking a short hop from M102 to NGC 5907. This highly elongated edge-on spiral galaxy conveniently lies between the comet and M102.

When your marathon passes through the realm of the galaxies in Virgo, step off the path to visit Comet 81P/Wild. This short-period comet orbits the Sun in 6.4 years and should look like a 9th- or 10th-magnitude Messier galaxy. Because the comet's tail hides behind its head, Wild should appear round like an elliptical galaxy.



Comet C/2007 Q3 (Siding Spring) glows at 10th magnitude among the stars of Draco. It passes just 2° from the galaxy M102 the weekend of March 13 and 14. *Astronomy: Roen Kelly*

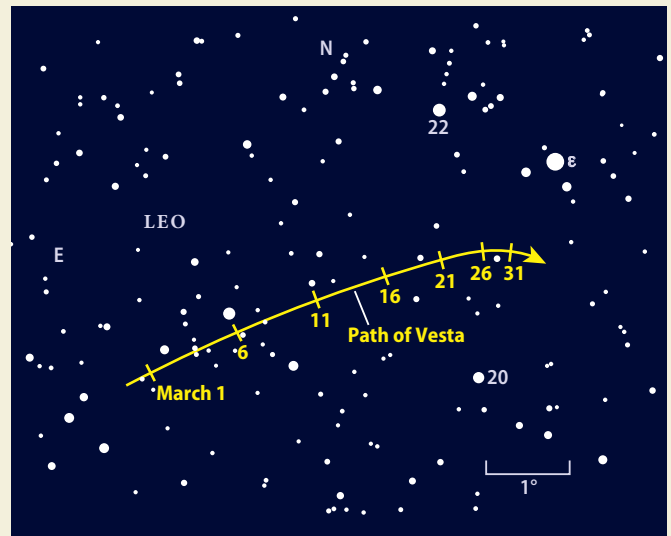
Locating asteroids

The king of beasts hosts asteroid royalty

In just 5 minutes this month, you can spot the sky's brightest asteroid. Head outside in midevening, and look two-thirds of the way up the eastern sky. Then, point your binoculars at the 1st-magnitude blue-white star Regulus, and scan from there toward Epsilon (ε) Leo, the 3rd-magnitude star at the tip of Leo's famous Sickle asterism. One of the points of light you saw along the way was 4 Vesta.

This 320-mile-wide main-belt asteroid masquerades among the stars of western Leo. Use the finder chart at right to zero in on its location. The arc-shaped part of the Sickle is slightly bigger than the field of view through most binoculars. Inside the arc, only four stars glow brighter than Vesta, which practically gives away the asteroid's location. Steady yourself against the side of a building or prop your elbows on a car to eliminate the shakes.

German astronomer Heinrich Olbers discovered Vesta in 1807. It was his second asteroid discovery (he spotted 2 Pallas in 1802) and the fourth overall. Vesta has a much lighter surface color than most asteroids, so it reflects more sunlight in our direction. This month, it fades from magnitude 6.2 to 6.8. Still, that's bright enough to shine through the veil of city lights when you use binoculars. Under a pitch-black sky, you can even spy it without optical aid.



Vesta roams among Leo's stars this month, in the northern part of the Lion's Sickle asterism. The 6th-magnitude asteroid glows brighter than most of its neighboring stars. *Astronomy: Roen Kelly*

nearly 2 hours after the Sun sets. The 0.6-magnitude planet lies among the stars of Virgo the Maiden, within a few Moon-widths of the 4th-magnitude star Eta (η) Virginis. By March 31, Saturn lies nearly 40° above the southeastern horizon at 10 P.M. local daylight time and is beautifully placed for observing through a telescope.

Saturn reaches its peak at opposition March 21. It then lies opposite the Sun in our sky and remains visible all night. It also lies closest to Earth at opposition, so it appears largest. Its disk measures 20" across the equator and 18" through the poles, while the rings span 44" along their major axis. Saturn's distance from Earth doesn't change radically this month, however, so you won't see any significant change in size.

At opposition, Saturn's rings tilt 3° to our line of sight. The rings were edge-on to our view last year, and we're now getting our first look at their northern face in 15 years. Although the tilt of the

rings generally grows larger this year, we're now in a temporary lull caused by the difference between the orbital inclinations of Earth and Saturn. In early March, the tilt registers 4°. This drops to 3° by late March and will dwindle to 2° from mid-April through early July. The rings will start to open again this summer and will widen to a 10° tilt by year's end.

Although the rings always fascinate observers, it's also worth tracking down Saturn's family of moons. Giant Titan glows at 8th magnitude and shows up through any telescope. This moon lies close to Saturn March 6 (northeast of the globe), March 14 (southwest), March 22 (northeast), and March 29 (southeast). When Titan swings farthest east and west of Saturn during each 16-day orbit, the moon lies a little more than 3' from the planet.

Three of Saturn's moons, Tethys, Dione, and Rhea, glow at 10th magnitude and show up easily through 6-inch scopes. All of them orbit



Jupiter returns to view before dawn in the latter half of March. Look for it low in the eastern twilight shortly before the Sun rises. *Astronomy: Roen Kelly*

closer to Saturn than Titan and so don't stray as far.

Iapetus wanders farther from Saturn than the other moons. It appeared brightest (10th magnitude) at greatest western elongation in mid-February. It passes less than 2' north of Saturn March 9/10, when it glows at 11th magnitude. That same night, Saturn's two inner moons, Mimas and Enceladus, appear near their best. You'll need a 10-inch scope to pick up these two

faint specks not far from the outer edge of Saturn's rings.

Jupiter reappears before dawn at month's end. On the 31st, it rises in the east about 50 minutes before sunrise. At magnitude -2.0, it shines bright enough to see through the twilight glow if you have a clear sky and an unobstructed horizon. The giant planet lies in Aquarius the Water-bearer, although you won't see any of this constellation's faint stars in the twilight. ☾

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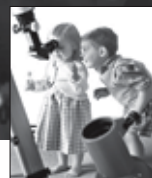
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ASTRONOMY'S 5 BIG QUESTIONS

Science looms closer than ever to solving the greatest mysteries in the universe. **by David J. Eicher**

A faint glow emerges as speckles of light cascade down a computer screen. In the control room of a remote observatory, an astronomer peers at the light, hoping once again to interpret the meaning of a distant exploding star. The landscape outside the observatory may as well be Mars. Broken rock and a craggy, frosty summit support steel domes that reach skyward, above most of the clouds. Standing on a 14,000-foot dormant volcano, the Keck Observatory on Mauna Kea, Hawaii, plays host to a wide range of astronomers who can visit the mountaintop every night, breathe in bottled oxygen, and rise above much of Earth's distorting atmosphere to gather scientific data.

On this night, astronomers are gathering light from exploding stars. Our galaxy, the Milky Way, contains more than 200 billion stars, just one of which is the Sun. Of the billions of others, the most massive stars —

heavyweights that live fast and die young — end their lives by blasting apart violently, casting material at supersonic speeds into the galactic neighborhoods that surround them. These supernovae are among the more violent, energetic events in the universe — since the Big Bang itself — and we owe our existence to them. Most of the elements in our bodies were created inside the centers of these exploding stars.

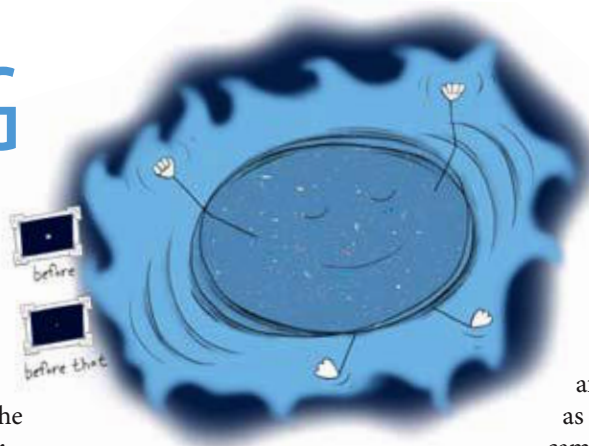
Not only did supernovae make life possible, but they are also beginning to tell astronomers a great deal about the universe's past. They can tell us how fast the universe is expanding and how much matter exists in it. The answers to these key questions will create a revolution in astronomy and in the human understanding of where we came from and why we are here.

David J. Eicher is the editor of *Astronomy*. He has been following big questions about the universe for 30 years.

1 HOW DID THE BIG BANG HAPPEN?

We know the universe began with a “Big Bang,” a powerful explosion of space-time that sent matter and energy reeling outward — not into empty space, but into nothingness. The evidence is abundant, from the underpinnings of Einstein’s general theory of relativity, to the detection of the cosmic microwave background radiation in the 1960s, to the confirmation of ripples in the fabric of ancient space-time from the Cosmic Background Explorer satellite in 1992. But just as with the rest of life, the devil is in the details.

When the Big Bang occurred, matter, energy, space, and time all formed, and the universe was infinitely dense and incredibly hot. The often-asked



question, “What came before the Big Bang?” is outside the realm of science, as there’s no way science can answer it. In fact, science says little about how the universe behaved until a fraction of a second after the Big Bang.

The universe cooled as it blew outward, however, leading to a moment of inflation, when the cosmos exploded in size in just a fraction of a second. As sensational as it sounds, inflation explains things that otherwise would be

difficult to understand. After inflating for a fraction of a second, the universe slowed down its rate of expansion but continued to grow, as it does today. It also cooled significantly, causing matter to condense from all the energy.

Chemistry has its roots deep in the history of the universe. At a key moment, about 1 second after the Big Bang, elements such as hydrogen, helium, and lithium came to be. After some 10,000 years, the temperature of the universe cooled to the point where gravity began to matter, magnifying ripples in space-time into structures we can see today. Some 370,000 years after that, scientists believe the universe changed from opaque to transparent. Matter and radiation finally separated.

The seeds for stars, galaxies, and planets were sown, and space and time began to resemble what we can see in the heavens today.

2 WHAT IS DARK MATTER?

Wild cards litter the cosmos. One of the strangest is that the universe contains some unseen form of matter — and plenty of it. To understand this dark matter, astronomers attempt to “weigh” the universe in a variety of ways. They observe the effects of dark matter on astronomical objects that vary from small to large.

The existence of dark matter was first suggested by the Dutch astronomer Jan Oort in the 1930s when he studied the motions of stars in the neighborhood of the Sun. Because the galaxy was not flying apart, he reasoned, enough matter must reside in the disk to keep the stars from moving away from the galaxy’s center. However, there didn’t seem to be enough visible matter to keep the stars from escaping. Oort postulated that, in the Sun’s neighbor-

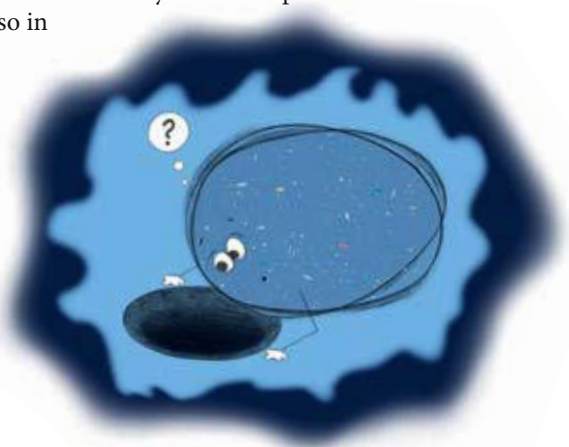
hood, 3 times as much dark matter existed as bright matter.

Stronger evidence came later as astronomers studied the glowing disks and halos of galaxies. Newton’s laws say velocities of stars rotating about a galaxy’s center should slow down dramatically the farther away they are from the center. But the stars in a galaxy orbit at the same speeds no matter how far out they are. The explanation for this is that massive spherical halos of dark matter surround the visible matter in galaxies.

Other clues for dark matter come from studying galaxy clusters. Also in the 1930s, American astronomer Fritz Zwicky discovered much larger clouds of dark matter in the Coma cluster of galaxies, about 300 million light-years from Earth. Zwicky found that visible matter must be only about 10 percent of the mass needed to keep the galaxies bound by gravity. Dark matter probably constitutes 90 percent of the matter in the universe.

So what is dark matter? That’s one of the greatest recent mysteries in the cosmos. It could be made of tiny particles called neutrinos; strange starlike objects dubbed brown dwarfs; white dwarfs; neutron stars; or black holes. Other possibilities include exotic particles like axions, massive neutrinos, photinos, or hydrogen gas floating between the galaxies.

Whatever it is, dark matter means a lot for the future of the cosmos. If enough of it is out there, it could eventually halt the expansion of the universe.



3 HOW DID GALAXIES FORM?

Astronomers know little about the earliest days of the universe. Did stars, galaxies, or black holes come first? The infant universe was a relatively uniform sea of several-thousand-degree gas and dark matter. Based on the echo of the Big Bang, astronomers think matter coalesced when the universe cooled and became transparent about 380,000 years after the Big Bang. Structures such as stars and galaxies likely formed about 500 million years after the Big Bang. But no one knows exactly how matter first clumped together.

Deciphering galaxy formation goes back to Walter Baade, who studied the stars in galaxies and tried to interpret how galaxies formed. One of the premier researchers at California's Mount Wilson Observatory in the 1950s, Baade discovered a group of stars around the Milky Way possessing little metal (in this case, metal is defined as elements heavier than hydrogen and helium). These stars are ancient, probably 11 billion years old. Metals that supernovae and other processes threw into interstellar space were eventually incorporated into younger stars in our galaxy.

Baade's discovery led to a model of galaxy formation in the 1960s nicknamed ELS, after Olin Eggen, Donald Lynden-Bell, and Allan Sandage. The ELS model says galaxies collapse as single objects out of gas clouds. As the gas falls in by gravity, it first forms a spheroidal halo. As more and more gas coalesces, it begins spinning and becomes enriched with metals, creating disks inside galaxies.

A different idea is the merger theory. Under this concept, protogalaxies —

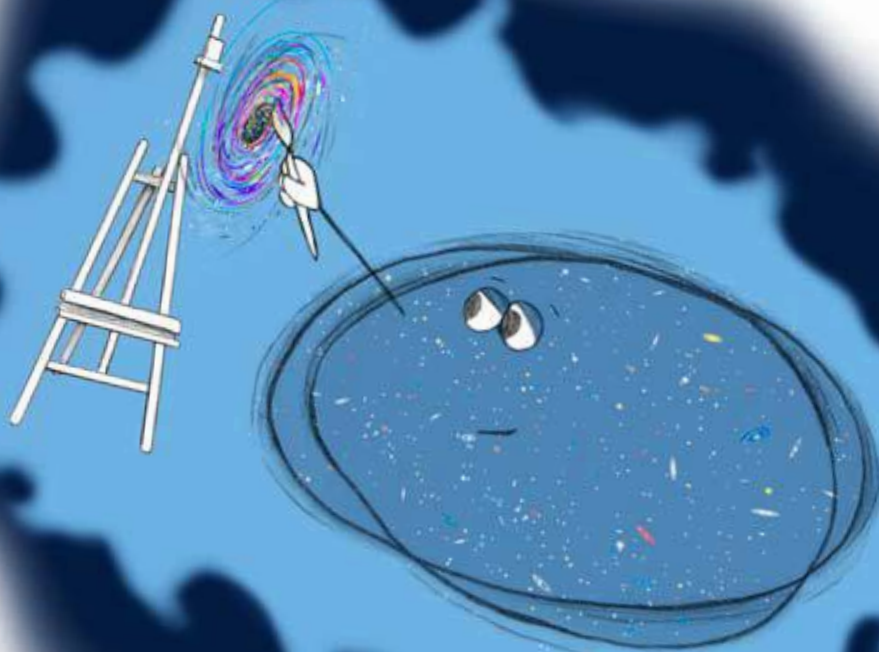
blobs of gas — gravitate together and merge to form the galaxies in the early universe. As time passes, galaxies of various sizes merge with other galaxies. Indeed, astronomers increasingly believe that many galaxies, perhaps the vast majority, formed when small gas clouds came together and merged into larger and larger structures as time went on. This is called the small-to-big path.

Evidence is coming together that galaxies form mainly through mergers. Several "deep fields" imaged by the Hubble Space Telescope, showing extremely distant galaxies, reveal numerous small objects that appear to be blob-like protogalaxies. They are likely the bits that clung together to form the larger, normal galaxies we see around us in the more recent universe. Some galaxy experts believe the Milky Way may have formed from the mergers of 100 or more small galaxies over time.

No one yet knows whether galaxies first came together as pockets of gas

and then formed stars, or whether stars formed from little pockets of gas and then aggregated into galaxies. A third possibility is that black holes formed first as dense pockets of matter that swept up bright matter around them, and surrounding galaxies then formed from the gas that the black hole didn't suck in. Black holes exist in the centers of many large and medium-sized galaxies. They are the driving engines in distant quasars (highly energetic infant galaxies). Astronomers now believe black holes probably inhabit the cores of nearly all large galaxies.

The James Webb Space Telescope, when launched in 2014, will attack the question of which came first. The project's "assembly of galaxies" study will aim to survey vast numbers of ancient galaxies to answer how they came together, perhaps with black holes as seeds that attracted matter.



4 HOW OLD IS THE UNIVERSE?

Over the past century, astronomers have deduced several ways to estimate the age of the universe. By using each of these methods, they can draw a bead on a region of time that probably represents the universe's age. The answer is much more accurate than it was 20 or 30 years ago, but it may never be certain. The age of the universe depends on the weight you assign to the method used to determine it.

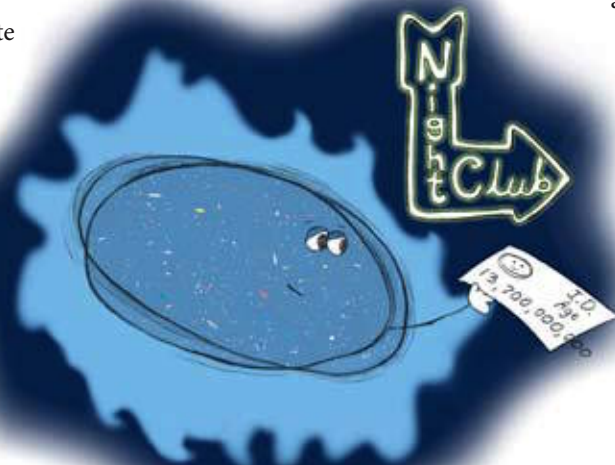
The most modern approach relies on using an almost magical number in astronomy called the Hubble constant. This number describes how fast

the cosmos is expanding — how fast galaxies are spreading apart from each other. To find the Hubble constant, astronomers observe distant galaxies and measure how fast they recede from Earth, as well as their distances. Scientists get the distances from measuring the brightness of known objects like variable stars of a particular type. They then determine the Hubble constant by

dividing the galaxy's speed of recession by its distance. Once they decide on a value for the Hubble constant, astronomers can determine the age of the universe by using a simple mathematical equation. The most often-cited figure for the universe's age using this method (widely thought to be the most precise) is 13.7 billion years.

Other approaches to calculating the universe's age attempt to measure the ages of the oldest objects in the universe. Astronomers can measure the decay of radioactive elements, so they can precisely measure the ages of the oldest rocks on Earth at 3.8 billion years and the oldest meteorites at 4.6 billion years, dating the solar system nicely. Applying this technique to old stars points to an age of the universe of 12 to 15 billion years, plus or minus 3 to 4 billion years. One study that measured uranium decay in ancient stars found the universe to be 12.5 billion years old.

Measuring the ages of ancient star clusters offers another avenue. By look-



Mysteries' histories

The current mysteries of the universe follow a long pedigree of apparently unexplainable phenomena that skywatchers have pondered ever since they first looked up. For millennia, before the evolution of science as a process, the questions remained basic and unanswerable. Are the stars twinkling windows into heaven, and the planets gods that move with free will? Throughout most of humanity's existence, the answers were more about cultural beliefs than the stars and planets people could see.

With the rise of scientific thought and the technological revolution of the past few centuries, we solved some of the mysteries. By the early 20th century, astronomers had sculpted a relatively accurate picture of the basics of stars and planets. But the identity of the galaxy and whether or not it constituted the whole universe was in question. Three steps greatly sharpened astronomers' views of the nature of the universe and the cosmic distance scale.

In 1912, Vesto M. Slipher found that many "spiral nebulae" were Doppler-shifted — that is, receding from Earth. Six years later, Har-

low Shapley devised a method of using variable stars called Cepheids to measure distance. And between 1923 and 1929, Edwin Hubble resolved Cepheid variables in the Andromeda Galaxy. Hubble demonstrated that the galaxy was terrifically distant and also established a proportionality between a galaxy's velocity away from Earth and its distance. Scientists found the key to unlock the distance scale of the universe, and they suddenly knew spiral nebulae were distant islands of stars and gas rather than local residents of the Milky Way.

As observations mounted and the technology of telescopes and detectors improved, astronomers' perceptions of the universe have sharpened dramatically. Although the details aren't all ironed out yet, it's now clear that the universe commenced with a Big Bang that sent matter reeling outward. With theoreticians working at an increasingly frenetic pace beside their observational colleagues, the race to tie together the details of astrophysics and cosmology into a grand view of the origin and evolution of the universe has heated up. Many significant findings have occurred in the past 20 years.

In 1992, for example, three big discoveries came in different areas of astronomy. Astronomers using the Cosmic Background Explorer satellite discovered fluctuations in the cosmic microwave background radiation — the echo of the Big Bang. These ripples in

Scientists recently solved one of the long-standing mysteries of planet Earth — the dinosaurs' extinction.

space-time provide a snapshot of the universe at the age of 380,000 years and may represent the seeds around which matter clumped into galaxies and stars a few hundred million years later.

That same year, astronomers detected a planet outside the solar system. Penn State astronomer Alexander Wolszczan found a

ing at the brightest stars in a globular cluster, astronomers can measure an upper limit for the age of the cluster. Recent studies of many globulars suggest an age of about 12 billion years for many of their oldest stars.

Astronomers can also measure the ages of white dwarf stars, the shrunken star remnants that are as heavy as the Sun but only as large as Earth. By finding the faintest, oldest white dwarfs, astronomers can pinpoint how long the objects have been cooling off. This method yields about 10 billion years for the age of the Milky Way's disk. Because the authors of that study suggest our galaxy's disk formed about 2 billion years after the Big Bang, that puts the age of the universe at about 12 billion years.

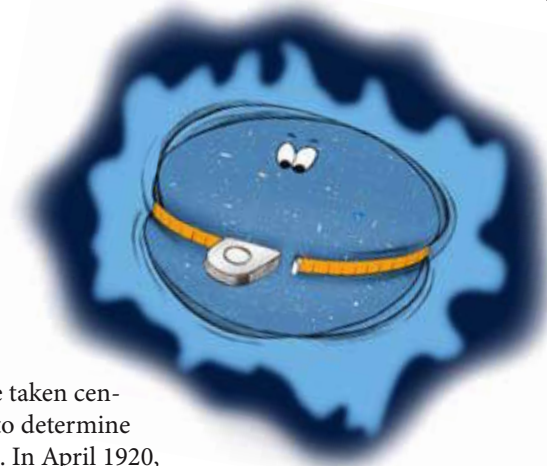
These techniques will continue to become more sophisticated and the window of uncertainty will continue to close, providing a pretty accurate estimate of the universe's age. However, most astronomers currently cite 13.7 billion years as the most likely estimate.

planetary system orbiting the millisecond pulsar PSR1257+12 in the constellation Virgo. Three years later astronomers found the first extrasolar planets orbiting Sun-like stars, and such systems now number in the hundreds.

And in our own solar system, David Jewitt and Jane Luu of the University of Hawaii discovered the first so-called Kuiper Belt objects, a previously hypothesized population of relatively small asteroids or comets beyond the orbit of Neptune. Astronomers now believe that at least 70,000 of these objects reside in the icy outer portion of the solar system.

In the 1980s, scientists solved one of the long-standing mysteries of planet Earth and one of its most celebrated life-forms — the dinosaurs' extinction. Geologists, planetary scientists, and astronomers collaborated to show that a subsurface impact scar in the Yucatán Peninsula was the result of the so-called K-T impact, the blow that killed the dinosaurs at the end of the Cretaceous period some 65 million years ago. Solving astronomical mysteries such as these not only enriches humanity's scientific knowledge, but it also reminds us how vulnerable we are to the quirks of the cosmos.

5 HOW BIG IS THE UNIVERSE?



Two great debates have taken center stage in the search to determine the size of the universe. In April 1920, astronomers Harlow Shapley and Heber D. Curtis argued about the scale of the universe in the great auditorium of the Smithsonian Institution's Natural History Museum in Washington, D.C. Curtis argued that the cosmos consists of many separate "island universes" — that "spiral nebulae" were distant systems of stars outside our Milky Way. Shapley argued that spiral nebulae were merely gas clouds inside the Milky Way. He further placed the Sun out near the edge of the very large galaxy, whereas Curtis believed the Sun to be near the center of the galaxy. Curtis was right about the large size of the universe but wrong about the Sun's place in the galaxy, whereas Shapley was wrong about the smaller universe and right about the Sun's location in it.

With the advent of various measured distances to galaxies, and with two camps arguing for different results on the Hubble constant — the expansion rate of the universe — astronomers staged a second great debate in 1996. The age and size of the universe are related, and both depend on the Hubble constant. In the same auditorium Shapley and Curtis used, galaxy researchers Sidney van den Bergh and Gustav Tammann argued over the question. Van den Bergh offered evidence suggesting a young age and relatively small size of the universe, while Tammann argued for an older, larger one. Astronomers are still limited both by assumptions and a lack of enough data to agree on the cosmic distance scale. The search for more information still races forward.

Despite this, astronomers can set some limits on what must be true, based on the observations of the past century. And by saying the size of the universe, we must first specify that we mean the size of the observable universe. If inflation theory is right, the universe could be much larger than that which we see. Using the most powerful telescopes, astronomers can see galaxies 10 to 13 billion light-years away. (A light-year equals about 6 trillion miles [10 trillion kilometers].) But the "horizon" of visibility in the cosmos stretches more than just some 20 to 26 billion light-years because space itself is expanding. So the edge of the observable universe must be at least 46 billion light-years away from us — that's called the comoving distance or particle horizon. The visible universe, however, is most likely a sphere of at least 93 billion light-years.

The story gets even weirder: Cosmic inflation may have happened in many places beyond the visible horizon and the limits of the space-time continuum we see. Other universes might exist beyond our ability to detect them. Even without them, we live in a universe that's at least 550 billion trillion miles (885 billion trillion km) across. ☛



Read the answers to the next five of astronomy's biggest questions online at www.Astronomy.com/toc.

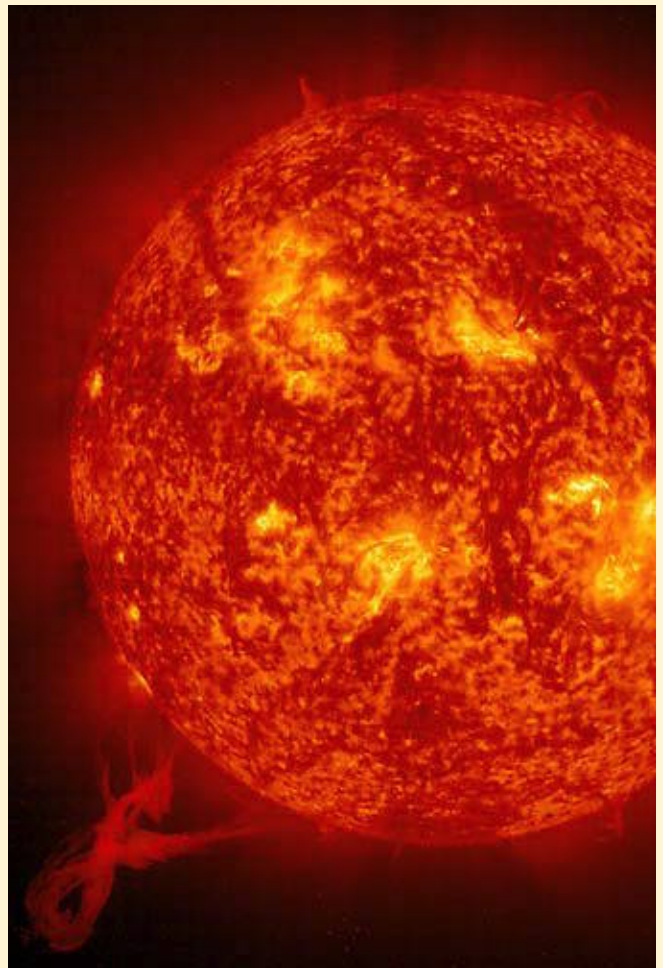
Stellar activity

Q: Do stars experience the same phenomena as our Sun, such as sunspots, prominences, solar wind, and flares? — Mark Narwa, Ottawa, Ontario

A: They sure do, at a strength that depends on the star's mass and age. There is no reason to think that the Sun would be special, and it isn't. Sun-like activity, though, is restricted to stars with masses below roughly $1\frac{1}{2}$ times that of the Sun. These stars have outer convection zones that, along with rotation, produce the strong magnetic fields necessary for flares and other such phenomena.

Scientists have been monitoring stellar magnetic activity (which generates sunspots and the like) for some 50 years. The prime indicator of magnetic activity is an emission line of light from ionized calcium that responds to magnetic heating of the chromosphere (the layer just above the bright solar surface). Roughly half the Sun-like stars show some kind of multiyear activity cycle, and many of the others vary erratically. In some, we see brightness variations caused by starspots swinging in and out of view with the stars' rotations. X-ray observations also reveal hot Sun-like coronas.

Two situations can greatly enhance the effects. One is close double stars with short orbital periods in which tidal effects speed up rotation; the other is low-mass red dwarfs in which we easily detect huge flares radiating across the spectrum. Activity diminishes with age because winds drag the magnetic fields outward and slow the stars with time. — Jim Kaler, University of Illinois, Urbana-Champaign



Flares, prominences, sunspots, and solar wind are not limited to our Sun. Other stars also portray such magnetic phenomena. SOHO (ESA & NASA)

TWO PEAS IN A POD?

Q: Could our solar system's habitable zone hold two earthlike planets? — John Lockwood, Washington, D.C.

A: Astronomers believe the solar system started out as a swirling cloud of gas and dust that circled the young Sun. Dust particles collected over millions of years into rocks. Eventually, they formed into asteroid-sized bodies, which then collided repeatedly until only a few large bodies — what we call planets — were left.

Earth ended up orbiting in the habitable zone (HZ), the region around a star in which the temperature of a planet can support liquid water on the surface. We think the Sun's HZ lies between 0.95

astronomical unit (AU, the distance between Earth and the Sun) and 1.4 AU. So Venus (at 0.7 AU) is too hot, and Mars (at 1.5 AU) is too cold. But what if Mars had formed a little bit closer ... could we have had two planets with liquid water?

Two earthlike planets in the HZ would have to be far enough apart so the gravitational pull between them would be weak enough to allow them to coexist peacefully. But, the HZ is only so wide. **Computer simulations of gravitational interactions between planets show that two Earth-mass planets would be stable if placed at both ends of the HZ's 0.95 AU to 1.4 AU range, as long as their orbits were almost circular.** If they were only as massive as Mars (so that

their gravitational attractions were weaker), three planets could fit in the HZ.

But, could two earthlike planets form in such a system? The discoveries of many extrasolar planets (some 400 at last count) have shown us the wide variety of planetary systems that are possible, and almost every new system found requires scientists to revise the rules of planet formation. Although we haven't discovered any planetary systems with habitable planets yet, data from the Kepler mission will increase our ability to detect planets similar to Earth. — Avi Mandell and Brian Jackson, NASA's Goddard Space Flight Center, Greenbelt, Maryland



Learn about exoplanet naming conventions at www.Astronomy.com/toc.

IO'S ERUPTIONS

Q: Do Io's volcanic eruptions create the electromagnetic torus between the moon and Jupiter? Could Io deorbit into Jupiter in the next several million years because of energy lost in these interactions?

— Douglas Kaupa, Edwards Air Force Base, California

A: There is no danger that Io will spiral down into Jupiter on a timescale of several million years.

Interactions with the jovian magnetic field have no significant orbital effect on Io, but they do have other major influences on the moon. Jupiter's magnetic field may contribute to internal heating of Io. As an electrical current passes through, resistance in the moon induces heating. The amount depends on the presence or absence of an ionian intrinsic magnetic field, or ionosphere.

The maximum amount of heating this mechanism can contribute is a small fraction of the heating from tidal interactions with Jupiter, Europa, and Ganymede. Such interactions ultimately drive Io's high level of volcanic activity.

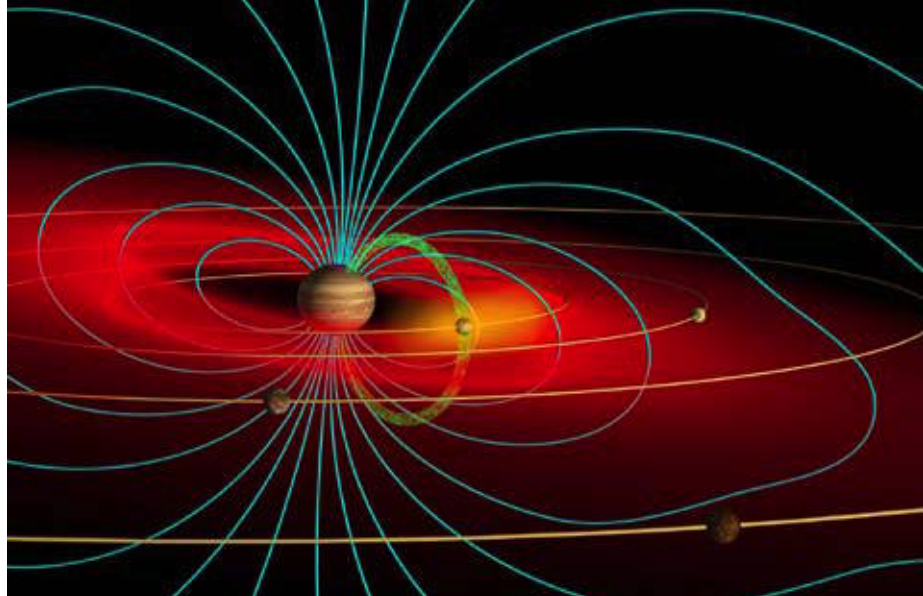
Io's volcanic eruptions do not create the electromagnetic torus. But they do contribute material to it. Io's volcanoes erupt material onto the surface and into a very tenuous atmosphere. Dust and gas consisting mostly of neutral atoms of sodium, potassium, oxygen, and sulfur that escape from Io form a cloud along Io's orbit.

Also, ultraviolet light or electron collisions break up the atomic material in the neutral cloud and Io's atmosphere. Jupiter's magnetic field immediately sweeps up, accelerates, and heats the resulting new electrons and ions. The material (sulfur and oxygen ions) is trapped in a plasma doughnut-shaped torus along Io's orbit. It moves with Jupiter's field and circles the planet in 10 hours, which is Jupiter's rotational period. — Ashley Davies, NASA's Jet Propulsion Laboratory, Pasadena, California

MAKING SENSE OF THE MULTIVERSE

Q: If we live in a multiverse, why do other universes not collide with ours? — Johnnie Smilinski, Winnipeg, Manitoba

A: Our observable universe is the region of space that we can see



John Spencer

The Jupiter-Io plasma torus (in red) is a result of Jupiter's magnetic field sweeping up material from Io's volcanic eruptions. As Io moves through the torus, interactions between Io and Jupiter power a huge electrical current that extends from one body to the other. This flux tube is shown in green.

today — all points in space in which the light has had enough time to reach us if it left those points at the Big Bang (13.7 billion years ago) or later. The multiverse consists of our observable universe and all of space outside of it — so, everything that is “out there.”

One of the most common meanings of “other universes” is “bubble universes” predicted by cosmological inflationary theory. They are regions of space where inflation was particularly successful, and these regions grow extremely fast. These bubble universes may have observers much like ours, and typically they are at great distances from us (much larger than the radius of our observable universe, which is about 50 billion light-years).

Any future collision between our observable universe and a bubble universe will presumably happen on cosmological timescales — tens of billions of years or longer. So we shouldn't expect a collision to happen next month. In fact, we hope it won't because the collision would progress with the speed of light and destroy our habitat at the same instant we would see it.

However, **it is also possible that our observable universe collided with another bubble universe in the past.** If that's the case, the cosmic microwave background (CMB) radiation may well hold relics of such a collision. Predicting the form of these relics and searching for them in the CMB is an area of current research. — Dragan Huterer, University of Michigan, Ann Arbor

GRAVITY VS. EXPANSION

Q: How is it that galaxies merge and collide but the universe is expanding and everything is moving away from everything else? — Justin Hammersley, Sterling Heights, Michigan

A: Whether or not galaxies merge depends on how strong the gravitational attraction is between the galaxies and whether the universe's expansion is more powerful than gravity. Gravity affects everything in the universe. The Milky Way Galaxy is gravitationally pulling on NGC 3370, nearly 100 million light-years away. The catch, however, is that the gravitational attraction between the Milky Way and NGC 3370 is so tiny that the universe's expansion can overcome it.

Over small scales, the force of gravity can beat out cosmic expansion and hold structures together, such as galaxy groups and galaxy clusters. Our Local Group of galaxies is an example of a grouping held together by mutual gravitation. And actually, the gravitational attraction between the Milky Way and Andromeda galaxies is strong enough that we're moving toward each other and will collide in some 5 billion years. — Liz Kruesi, Associate Editor

Send your questions via e-mail to: askastro@astronomy.com; or write to Ask Astro, P.O. Box 1612, Waukesha, WI, 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

July 11, 2010

Totality crosses Easter Island

Here's what you need to know if you're planning to see July's solar eclipse. **by Joel Harris**

July 11. For any serious eclipse-chaser, this date carries great significance — and with it, either fond memories of an exceptionally long totality or the bitter disappointment of a clouded-out event. And while the July 11, 2010, total solar eclipse is neither as long nor as favorably located as the great eclipse of July 11, 1991, it nevertheless offers some highly enticing — even exotic — viewing opportunities.

Every eclipse presents normal meteorological challenges to would-be observers. But July's eclipse across the southern Pacific Ocean and a small portion of southernmost South America will be especially daunting to reach.

The right places, the right times

The central eclipse track begins at sunrise, 18h15m Universal Time (UT), approximately 435 miles (700 kilometers) southeast of the South Pacific island of Tonga. The lunar shadow then moves in a northeasterly direction. Six minutes after touching Earth's surface, it makes the first of a precious few landfalls.

The island of Mangaia, part of the Cook Islands group maintaining a “free

association” with New Zealand, experiences 3 minutes and 18 seconds of totality, with the Sun positioned 14° above the horizon. Mangaia is the southernmost of the 15-member group, being second in area only to Raratonga (population 14,153), which regrettably lies 15.5 miles (25 km) outside the southern limit of the path of totality. The name Mangaia means “terraced” in the Raratongan language; indeed, numerous terraced cliffs rising above its shoreline mark the island's boundary.

Those eclipse enthusiasts expending the effort to go to Mangaia will most likely fly from home to Raratonga, and then catch one of the short, 40-minute flights on Air Raratonga that land at Makatea Airport. With limited infrastructure and transportation, the best advice is to join an organized eclipse tour operated by one of the experienced astronomical travel companies that specialize in such trips.

As the lunar umbra (the dark inner shadow under which totality occurs) races across the vast Pacific, it passes tantalizingly



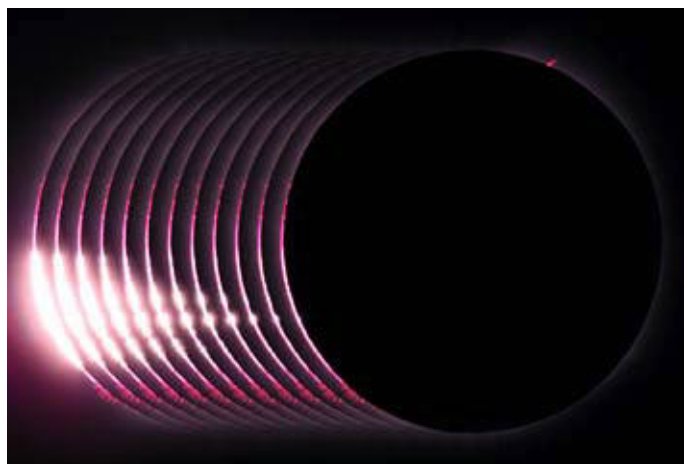
For the July 2010 eclipse, many travelers will opt for a cruise. Being afloat, as during the March 29, 2006, eclipse near Greece (above), allows you to change course. Holley Y. Bakich

close — 12.4 miles (20 km) — to Tahiti. That island's southern edge experiences a 99.6 percent partial eclipse, and its capital, Papeete, gets a 98.4 percent one. To make up for this near-miss, South Pacific observers need only wait until June 6, 2012, when the second of this century's transits of Venus will be visible from French Polynesia.

Nineteen minutes after passing over Mangaia, the umbra makes its second landfall, crossing over a number of the small, highly isolated atolls (constituting the largest chain of such “islands” in the world) in the Tuamotu Archipelago. Among the larger atolls within the eclipse path are Hikueru (population 125), Amanu, Hao, and Tatikutu.

All but Amanu possess small airstrips, serviced by Air Tahiti from Papeete. However, as in the case of Mangaia, the infrastructure on these islands is minimal. Only the most self-sufficient eclipse expeditions (most likely cruise ships) will be able to successfully support dedicated eclipse-chasers at

these venues. Perhaps it's a warning that the former name for the Tuamotu Archipelago was “The

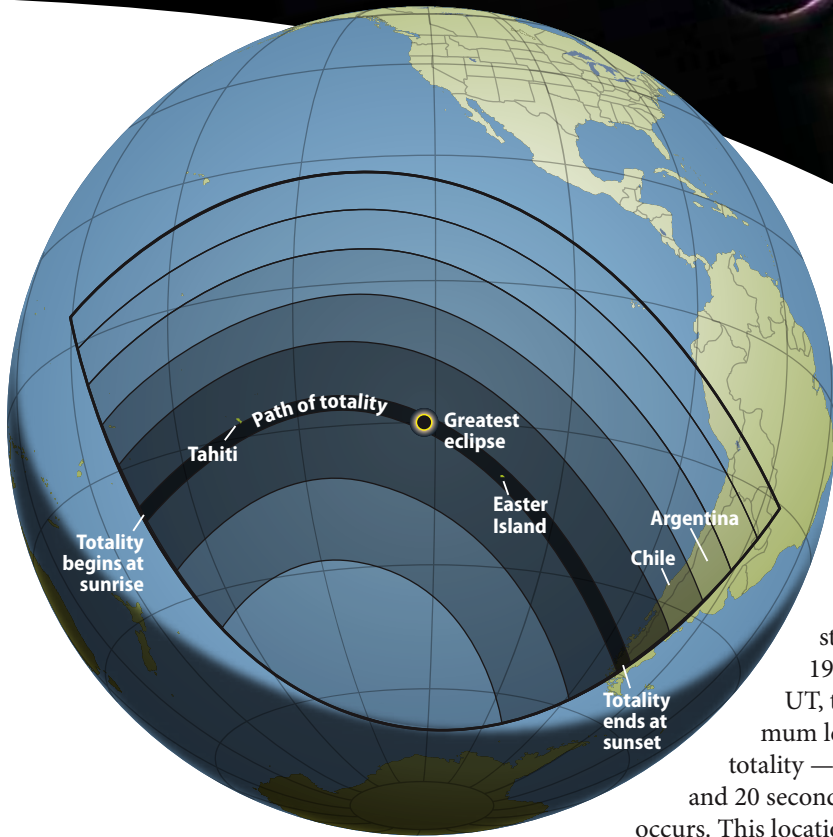


This series of exposures just after the first diamond ring shows the progression to the August 1, 2008, eclipse's total phase. The small, brilliant dots of sunlight are Bailey's beads, named for British astronomer Francis Bailey (1774–1844), who first described them. Tunç Tezel



©iStockphoto.com/Dan Kite

Each total solar eclipse contains memorable moments and features. This montage of the March 29, 2006, event captures everyone's favorites: both diamond rings (second image from the left and the second from the right) and the solar corona (third image from the right).
Ian Wardlaw



The path of totality

July 11 covers a narrow strip of the South Pacific, passing near Tahiti and over Easter Island before ending in southern South America. *Astronomy: Roen Kelly*

Dangerous Archipelago.” Those serious eclipse-chasers traveling to Hikueru, Hao, or Tatikutu atolls will witness between 4 minutes and 20 seconds and 4 minutes and 35 seconds of totality, with the Sun 30° to 36° up in the northeast.

Many travelers to this region will opt for a cruise. *Astronomy* magazine has teamed up with MWT Associates to offer a 14-day cruise to the Marquesas Islands. Senior Editor Richard Talcott will be the astronomer on board.

Totality over Easter Island

Leaving the Tutamotus behind, the Moon's shadow now traverses more than 2,050 miles (3,300 km) of open ocean, for nearly 90 minutes. Halfway through this

Joel Harris is the founder and president of Twilight Tours, Inc., of Westlake Village, California.

stretch, at 19h33m31s UT, the maximum length of totality — 5 minutes and 20 seconds — occurs. This location has coordinates of longitude 121°53' west and latitude 9°45' south. After that, the shadow arrives at what most people consider to be the most isolated inhabited landmass on the planet: Easter Island.

Tour guides and travelers already have expressed a great deal about the prospect of a total solar eclipse sweeping over Easter Island. Some articles, e-mails, and Internet postings give a reasonably accurate representation of the anticipated weather, hotel accommodations, and logistical conditions during the week before the eclipse.

Lamentably, there also have been some exaggerated reports that cast the islanders in a negative light. These purport to quote indigenous residents and the local government of Rapa Nui (the Polynesian name for Easter Island). The alleged reports state that authorities will forbid tourists from going to the island or minimize their numbers. Not true.

My colleague Gregory Buchwald from Chicago and I conducted an in-depth survey of Rapa Nui in August 2009. We visited potential observing sites, noted daytime weather patterns, and checked hotel availability.

If I were to describe Easter Island using few words, it would be: Think of Tahiti, Hawaii, and Latin America blended into a single culture. When the influx of eclipse-chasers hits in July, tourists will likely stretch hotels and tourist services to the limit of their capacity.

Notwithstanding the overt aspects of Easter Island's location and culture, the island's main attractions are the more than 850 massive, brooding monolithic stone heads, or Moai. Some of these huge statues measure more than 35 feet (10.7 meters) high and weigh more than 20 tons (18,000 kilograms).

The Moai represent the embodiment of the Rapa Nui people, their long heritage, and their familial lineage. If you are planning to travel to Easter Island you must be mindful of the absolute sanctity of the Moai and the *ahu*, or pedestals, on which they sit.

During my visit, one of the 3,800 native residents explained how seriously



This chart shows the sky over the point of greatest eclipse July 11, 2010. The Sun and Moon sit at the center of Gemini the Twins. Mercury, at magnitude -0.8 , stands nearly 15° due east of the Sun. Venus, blazing away at magnitude -4.1 , lies 42° east of the Sun. *Astronomy: Richard Talcott and Roen Kelly*

they take the Moai and their *aku aku* (supernatural spirits). Our guide also mentioned that the islanders weren't particularly amused by the concept of martians coming to their island. This was an obtuse reference to the scene depicted in the 1996 Tim Burton film, *Mars Attacks*. In the production, one of the alien saucers produces a huge bowling ball and knocks over a line of Moai, like so many bowling pins. I suggest tourists avoid any references to this film scene.



Clouds were a problem throughout China during the July 22, 2009, total solar eclipse. Although the path of totality crossed densely packed populated regions, few observers got a clear view of the event. *Yifei Wang*

For the eclipse, a large number of suitable viewing sites exist. Chief among them are Anakena Beach, the capital town of Hanga Roa, and Tongariki on the south coast. The potential problem with some of these sites, however, is the number of eclipse enthusiasts eager to get their personal version of the ultimate Kodak moment — the fully eclipsed Sun suspended over a silhouetted row of Moai. On Easter Island, totality will last 4 minutes and 41 seconds. Totality begins at approximately 2:11 P.M. local time (20h11m UT) while the Sun stands 40° above the north-northwestern horizon.

South American shadow

After crossing Easter Island, the Moon's shadow embarks on another long open-water trek of almost 2,300 miles (3,700 km). The final landfall of this eclipse is in the lake region of extreme southern Chile and southern Patagonia in Argentina. The most feasible observing site here is the tourist town of El Calafate, located on the eastern side of the majestic southern Andes Mountains.

The main challenge at El Calafate is the extremely low altitude of the eclipse.



Just imagine a daytime view with Easter Island's famed Moai (stone sculptures) in silhouette — then add the totally eclipsed Sun. If it's clear over Easter Island July 11, 2010, you could record just such a scene. *Stéphane Guisard/www.astrosurf.com/sguisard*

The Sun will float only 1° above the Andes' silhouetted skyline, with a total phase lasting 2 minutes and 47 seconds. At such a low altitude, the probability of seeing totality through potential intervening clouds or haze will be low.

What are your chances?

As to the overall weather prospects for the eclipse, I asked Jay Anderson, a retired senior meteorologist from the Prairie Weather Center in Winnipeg, Manitoba. Anderson is a well-known eclipse weather expert. He says the primary locales to maximize the chance of seeing totality are the Tuamotu atolls, followed closely by both Mangaia and Easter Island.

The probabilities of having clear weather are around 55 percent in the Tuamotos and between 48 and 52 percent for Mangaia and Easter Island. The prospects at El Calafate are similar to Mangaia, but remember the Sun will be low at totality so clouds may obscure your view.

If the weather is good, and you photograph the eclipse, be sure to send in your best shots to Astronomy.com as soon after the event as you can. Wherever you elect to go for next July's total eclipse, make sure your travel plans are solidly confirmed, travel light, and keep a flexible attitude regarding your timetable. ☿



View the story "Your 20-year solar eclipse planner" at www.Astronomy.com/toc.



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Astro-Tech's AT6RC offers great imaging on a budget

High-quality optics and mechanics make this 6-inch Ritchey-Chrétien telescope one astroimagers will appreciate. **by Phil Harrington**

For more than a century, Ritchey-Chrétien (RC) reflectors have been the most common type of telescope installed in professional observatories. The design combines a hyperbolic concave primary mirror with a hyperbolic convex secondary mirror to produce tack-sharp images free of coma, astigmatism, and spherical aberration. Amateur astronomers, however, have been slow to respond to RCs. Because their mirrors have curves that are difficult to figure, RCs can be expensive to make.

Recently, Astronomy Technologies (Astro-Tech), based in Norman, Oklahoma, did what many thought was impossible: offer RC optics in an affordable package. The company's 6-inch f/9

AT6RC includes enhanced aluminum mirrors coated with quartz, a dual-speed Crayford-style focuser, a Vixen-style dovetail rail for attaching the tube to many of today's most popular mounts, and a standard finder scope shoe — all for an amazing \$795.

The scope does not include a mount, a finder scope, or eyepieces. I supplied my own for this test.

It is important to note that Astro-Tech designed the AT6RC specifically for astrophotography using digital single-lens reflex (DSLR) cameras and other imagers with large chips. An observer can use it visually, but the real strength behind the RC design is its flat photographic field. This eliminates the “star bloat” that plagues photos taken with many other optical designs.

One reason RCs are not as suitable for visual observing as some other designs is their comparatively large central obstructions created by their secondary mirrors. Central obstructions decrease image contrast. The larger the obstruction, the greater the impact.



The two-speed Crayford focuser offers a 10-to-1 reduction between coarse and fine focus adjustments. It accepts 1¼" and 2" eyepieces.

In the case of the AT6RC, the central obstruction measures 3 inches (7.6 centimeters) across, or 50 percent of the aperture's diameter. That ratio is noticeably larger than comparably sized Schmidt-Cassegrain and Maksutov-Cassegrain designs. The AT6RC's enhanced optical coatings offset part of the problem, but visual contrast still will suffer. Astroimagers can correct photographic contrast easily with software during processing, which is why photographers are more concerned with sharpness.

Contact information

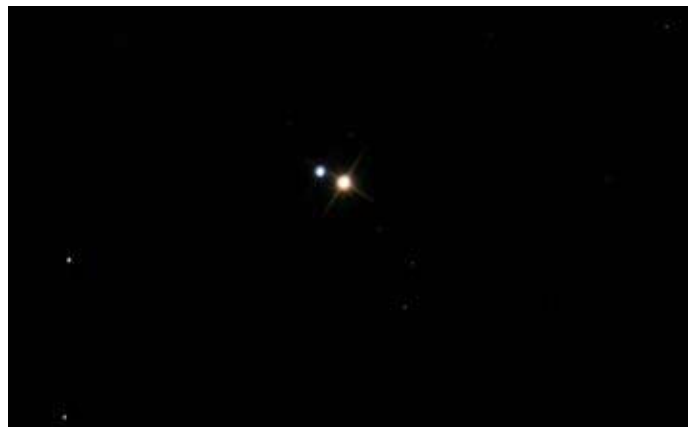
Astronomy Technologies

P.O. Box 720013

Norman, Oklahoma 73070

[e] info@astronomytechnologies.com

[w] www.astronomytechnologies.com



The Hercules Cluster (M13, left photo) and Albireo (Beta [β] Cygni) appear sharp in these images the author took through the Astro-Tech AT6RC. Phil Harrington captured both by attaching his Canon XTi digital SLR to the telescope's focuser and setting the digital speed at ISO 400. He created the Hercules Cluster shot by stacking fifteen 30-second exposures. The image of Albireo was a single 10-second exposure.



Astronomy Technologies' AT6RC Ritchey-Chrétien telescope targets imagers who use digital SLRs and other large-chip cameras. Equipment photos: Astronomy; William Zuback

High-quality impressions

The test scope arrived collimated. Had adjustment been necessary, I could have referred to the included instruction sheet to fine-tune the secondary mirror's three screws. The guidance, however, specifically warns, "Do not adjust the six mirror-alignment screws on back of the rear cell as this will void your warranty."

The AT6RC weighs just 13 pounds (5.9 kilograms) and measures only 19.25 inches (48.9cm) long, not counting the extension tubes. The fit and finish are excellent. All interior surfaces, including the eight well-designed baffles, are flat black. Proper baffling and blackening are crucial in RCs to keep stray light from infiltrating the optical path.

The AT6RC's Crayford focuser accepts both 1¼" and 2" eyepieces. Both adjustments — the coarse focus and the 10-to-1 reduction fine focus — move smoothly. Every photographer will appreciate the focuser drawtube's numerical scale, which makes returning to a specific setting easy. A locking screw ensures the focuser won't shift.

The focuser drawtube has 1.34 inches (3.4cm) of travel, which alone is not long enough for cameras and eyepieces to focus properly. That's why the AT6RC comes with two 2"-long extension tubes. All of my eyepieces focused perfectly with one tube in place, but for photography, my Canon XTi digital SLR needed a little more out-focus. Together, however,

both tubes proved too long. Once I combined my own 1" extension with one of the supplied 2" tubes, focusing was easy. Accessory suppliers offer a matching 1" tubes for less than \$35.

While the focuser worked smoothly, it sagged slightly under the weight of my Canon XTi. You can minimize the sag by checking that the focuser's tension screw is tight. If that screw is loose, the drawtube also will move too easily for accurate focusing. Be certain that you screw the focuser and extension tubes together firmly. The focuser rotates, which is handy, but make sure its lock ring is tight.

Sky-testing the AT6RC

Turning the test scope skyward quickly revealed the first-class quality of its optics. Images stayed crisp beyond 300x across the full field of view. Coma, a



The AT6RC's large central obstruction (50 percent of the diameter) makes this scope better suited for imaging than for visual observing.

Product specifications

Astro-Tech AT6RC

Type: Ritchey-Chrétien reflector

Aperture: 6 inches

Focal length: 1,370 millimeters

Focal ratio: f/9

Length: 19.25 inches (48.9 cm)

Weight: 13 pounds (5.9 kg)

Included: Dual-speed 2" Crayford-style focuser, Vixen-style dovetail rail, two 2"-long extension tubes, standard finder scope shoe

Price: \$795

problem inherent with some catadioptric optical designs, was minimal, as was spherical aberration.

The AT6RC did a great job resolving small-scale objects, such as globular clusters, lunar features, and closely spaced double stars. My view of the Double Double (Epsilon [ε] Lyrae) especially impressed me. All four stars remained clearly split even when I moved them to the edge of my eyepiece's 82° apparent field. More demanding binaries also showed clean splits.

A bargain astroimaging tool

Whether taking photos of the Moon or deep-sky objects, the AT6RC proves to be a versatile instrument. Its compact size makes it easy to transport, while its aperture is large enough to capture impressive images of a variety of targets. If you are looking to expand into photography and want the benefit of a Ritchey-Chrétien's razor-sharp images without breaking the bank, I highly recommend the AT6RC. ☛

Phil Harrington is an Astronomy contributing editor.



Secret Sky
by Stephen James O'Meara

Measure the Moon

Don't let psychological tricks fool you when determining the Moon's size.

In my January column, I challenged readers to look for some of the finest naked-eye features on the Moon during lunar perigee — when the Moon is closest to Earth in its elliptical orbit. But have you ever wondered if we can tell whether the Moon is at perigee or apogee (when it's farthest away) using only our unaided eyes?

The problem is that during the night the Moon sails across the vast vault of the sky unrivaled in size. During the day, only the Sun (which we should never look at without proper protection) compares to the Moon in apparent size. Furthermore, when the Moon lies just above the horizon, a physiological effect called the Moon illusion causes its image to swell in the mind's eye. And when the Moon stands high overhead, another illusion makes it appear smaller than it should.

Nevertheless, noticing a change in the Moon's apparent size shouldn't be too difficult. At perigee the Moon lies some 25,000 miles (40,000 kilometers) closer to Earth than it does at apogee, making it appear roughly 10 percent larger. That's the equivalent of a quarter's size compared to a nickel's.

Few would argue that a Full Moon rising attracts attention. But I've noticed a greater "Wow!" factor when peo-

ple see a perigee Full Moon rising. Arguably, then, we can detect the difference, at least on a subconscious level. But can we perform a more reliable test?

Two thumbs up!

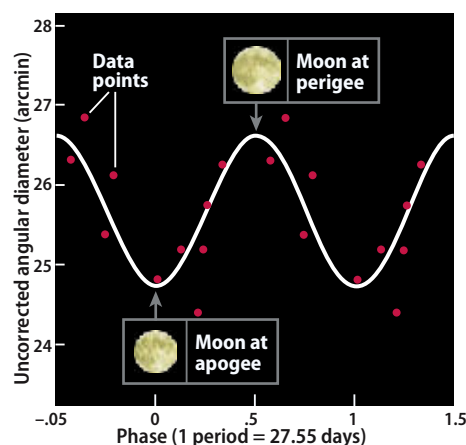
Over the years, I've enjoyed experimenting with the challenge noted above and have found a simple solution. Just go outside when the Moon is visible in the daytime sky, hold out your thumb at arm's length, and point it toward the Moon. With both eyes open, first focus on your thumb, then on the Moon. What happens?

When you shift focus, your thumb should look doubled (the effect of parallax). Depending on your dominant eye, one of the thumbs will appear transparent enough for you to project the Moon against the phantom thumbnail! If you do this when the Moon is at apogee, then at perigee, you can detect a noticeable difference in the size of the Moon compared to the size of your nail.

A precision experiment

Independently, Texas A&M University astronomer Kevin Krisciunas has also given this matter some thought. While teaching his students, Krisciunas began to wonder about the ancient Greeks and naked-eye

By pointing his homemade device at the Moon, Kevin Krisciunas emulates inventor Levi ben Gerson (1288–1344), famous for measuring the varying sizes of the Moon, the Sun, and various other stellar objects. Sandra Rodriguez Krisciunas



The varying size of the Moon over time became clear to Kevin Krisciunas, who visually measured and graphed its changing sizes with homemade equipment. Kevin Krisciunas, *Astronomy*; Roen Kelly

Renaissance observers who long knew that the Earth-Moon distance varies — knowledge deduced primarily from observations of the Moon's size during total and annular solar eclipses.

But those observed changes in size could have been due to the variable Earth-Sun distance or Earth-Moon distance, or both. "So," Krisciunas pondered, "can we measure (without any lenses) the Moon's correct angular size, and that the Earth-Moon distance varies by plus or minus 5 percent?"

To find out, Krisciunas designed an experiment. Using a hole punch, he took a thin piece of cardboard and made a hole 0.24 inch (6.2 millimeters) across. He then attached the cardboard to a cross piece that could slide along a yardstick. By simply pointing the yardstick at the Moon and moving the cardboard back and forth, Krisciunas could match the Moon's angular size with the hole's angular size.

A hole 0.24 inch across, held 27.05 inches (687mm) from the eye, should subtend an angle of 31 arcminutes — the Moon's average angular diameter. But



“Have you ever wondered if we can tell whether the Moon is at perigee or apogee using only our unaided eyes?”



Kevin Krisciunas shows off his homemade Moon-measurer, based on Gerson's staff of Jacob. Sandra Rodriguez Krisciunas

that's not what he found. Using the following equation:

$$\theta = 60 \times (h/d) \times (180/\pi)$$

where θ is the Moon's angular extent in arcminutes, h is the diameter of the hole (0.24 inch), and d is the distance of the hole from the eye (which he determined to be 32.56 inches [827mm]), Krisciunas determined θ to be only approximately 26 arcminutes.

As Krisciunas discovered, and as the late Marcel Minnaert suggested in his 1954 book *The Nature of Light and Color in the Open Air*, psychological factors that are little understood play a role in perceiving the Moon. Indeed, Minnaert stated that if you look at the Moon through an aperture in a piece of cardboard with one eye, the Moon will appear smaller than when viewed directly with two eyes.

A Correction factor

Undaunted, Krisciunas took a disk 0.358 inch (9mm) in diameter and taped it to a door 32.8 feet (10 meters) away, so that its angular size would equal 31 arcminutes. When he looked at that disk through the 0.24-inch hole at a distance of 32.3 inches (821mm), he found a match of angular size (26 arcminutes). If we therefore divide the Moon's true average angular extent (31 arcminutes) by the measured average (26 arcminutes), we arrive at a correction factor of 1.2.

“If I take my uncorrected measures of the angular

diameter of the actual Moon and multiply them by 1.2,” Krisciunas says, “I get, on average, the correct angular size of the Moon accurate to plus or minus 0.8 arcminute. I've convinced myself [that] with my very simple equipment I can measure the variation of the Moon's angular size and eliminate systematic errors with my correction factor” (see graph on page 58).

Krisciunas cautions, however, that everyone's eyes are different; observers may have to find their own correction factors. He'd like to know if you get the same



Sticking tape to his thumb, the author managed to semi-accurately determine the Moon's size, with an error factor of only 6 percent. Can you do any better? Stephen James O'Meara

correction factors for objects that are demonstrably 31 arcminutes wide, using a sighting hole that is about 0.24 inch.

If a 0.35-inch circle viewed at a distance of 32.8 feet comes out to 31 arcminutes, then your correction factor is 1. If you derive an angular size less than 31 arcminutes, then your correction factor is greater than 1, like Krisciunas'.

Just curious

After speaking with Krisciunas, I took a piece of 1/2-inch masking tape on which I had penned a couple of measurement lines, and placed it on my thumbnail. I went outside, casually held my thumb up to the Moon, and measured the Moon's north-south extent against the ruled lines. Next I measured the distance from my dominant eye to my extended thumb. Back inside, I measured the Moon's projected size on the tape with a ruler.

The result? At that date and time, the Moon was 32 arcminutes in apparent diameter. My measurement? 34 arcminutes, off by only 6 percent ... not bad for a casual experiment! I know I can do better, and I bet you can, too!

Krisciunas and I would love to hear about your experiences. Send reports to krisciunas@physics.tamu.edu and someara@interpac.net. ☺



Browse the “Secret Sky” archive at www.Astronomy.com/OMeara.



Evening Stars

by David H. Levy

Old Hickory and old friends

From Jackson Hole to Jacksonville, astronomy remains a fun and popular pursuit.

Not until last fall did I realize the ubiquity of the name Jackson. While the seventh president of the United States may be the name's most illustrious bearer, two important American cities also share it: Jackson Hole, Wyoming, and Jacksonville, Florida. The Florida city honors the military governor of the Florida territory (and future president) Andrew Jackson, while Jackson Hole derives its name from another Jackson entirely — a fur trader, David E. Jackson. Both places gave me the honor, in the span of just a few days, of participating in their International Year of Astronomy activities.

Yellowstone, dark sky

Named for a valley that divides the Grand Teton and Yellowstone national parks, the city of Jackson Hole, Wyoming, has a vibrant astronomy club. Because of Jackson Hole's elevation, its night sky is particularly dark and crisp. The Jackson (Hole) Astronomy Club takes advantage of the many clear nights to show off the sky's major, and even not-so-major, attractions.

The club's more advanced members have observatories from which they gaze at the sky on clear nights, but they see fostering interest in astronomy as one of their most important activities. Their monthly schedule is crowded with schoolyard star parties. One of their most active members, Walt Farmer the astro-cowboy, has an observatory filled with signatures and drawings by its many visitors. My own meek addition, a traditional "smiling comet," appears now on the building's north wall. The artwork also gives children the chance to express how

they see the connections between art and science while they peer into the night.

It's almost impossible to live in Jackson Hole without having some appreciation for the fabulous wilderness that surrounds it, particularly to the north where the triple volcanic calderas of Yellowstone protect the city from a huge seething subterranean mass of liquid rock. By far the largest volcano system in the United States, it remains active with geysers of boiling water. They erupt regularly like Old Faithful, or almost continuously like the Clepsydra Geyser that stands near a cache of boiling mud.



Mike D. Reynolds, dean of liberal arts and sciences at Florida State College at Jacksonville, introduces a speaker at Astronomy Day. David H. Levy

Coast-to-coast astronomy

Just 4 days after I returned home to Vail, Arizona, from Jackson Hole, I departed again for my first visit to Jacksonville, Florida. This city is special because it marks a place where the Sharing the Sky Foundation, in its effort to inspire the next generation to enjoy the stars, recently donated a 14-inch Schmidt-Cassegrain telescope to the former Florida Community College at Jacksonville (now Florida State College at Jacksonville [FSCJ]). This instrument will reside in an out-of-town observatory, which should attract astronomy students from all over the state.

Although Florida does not have the darkest sky in the world, its exceptionally steady views have allowed top-notch astrophotographers like Don Parker to flourish. And Mike D. Reynolds, FSCJ's dean of liberal arts and sciences and a contributing editor of *Astronomy*, provides a high-quality astronomy program for students. He emphasizes meteor showers and eclipses — two areas of astronomy about which he is passionate.

"Dr. Mike" designs programs so they can reach a broad range of students. He tries to keep them as balanced as possible, mixing practical observation with theoretical aspects. Beyond that, he has thrown open the college's doors for a vast array of astronomical outreach programming. For instance, on a single afternoon this past October, he arranged for six major speakers to talk about divergent aspects of astronomy, from astrophotography to higher math.

His program's healthy observing component was evident October 3, when many of us took advantage of the clear Florida sky with several telescopes from the Northeast Florida Astronomy Society. We enjoyed good views of Jupiter, as well as the Moon a few hours short of full and a few days shy of its much-anticipated impact with the LCROSS spacecraft. By encouraging us to study the Moon at this time, Reynolds emphasized the connection between an amateur's casual delight in the night sky and a major national space effort.

Just as the same name belonged to a humble fur trader and a president of the United States, so does the word astronomer include the novice simply looking up and the professional discovering new worlds. After my visits, it's clear these towns share more than just a name. ☐



Browse the "Evening Stars" archive at www.Astronomy.com/Levy.



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Astro-Physics' 2.7" to 6x7 Outer Bayonet Adapter is for astroimagers who couple large-format CCD cameras and full-frame digital SLRs to focusers and accessories that have the female Astro-Physics 2.7" thread. The adapter has black anodization with flat-black internal baffles.

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Price: \$2,195
[t] 201.995.0051
[w] www.leicacamerausa.com



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Niagara Falls, New York

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NEXT MONTH
in the April issue



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Fifty years after Frank Drake quantified life in the universe, here's where we stand.

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The frigid edge of our planetary system has launched a white-hot revolution in understanding the solar system's origin and evolution.

Who was Thomas Harriot?

England's contemporary of Galileo observed the Sun, the Moon, and Jupiter's satellites through an early telescope.

Imaging prehistoric sunrises

With a bit of detective work and graphic manipulation, astrophotographer Frank Zullo visualizes sunrises that prehistoric skywatchers saw.

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Jim Burr

President and Founder, JMI Telescopes

Jim Burr, founder of JMI Telescopes (Jim's Mobile, Inc.), grew up on a farm in Minnesota that had some 15 cows, 200 chickens, and a big garden. "We got along, but things were tight," he says.

Burr developed an interest in astronomy as a boy after listening to an astronomy presentation by Phillip Knox, the "Horkheimer of the first half of the 1900s." Knox would travel the country and show slides of the universe. Often his talks were the only contact people had with astronomy, Burr says. "Remember, we didn't have *Star Wars* in the 1940s and '50s. JMI would not exist today if it were not for that man."

In 1979, while Burr ran a mobile TV repair shop, he took a class in astronomy and subsequently built a 10-inch f/15 classic Cassegrain. It was so powerful that waiting for the "wiggling" to stop during focusing was a nightmare. So, in 1982 he solved the problem by developing and patenting MotoFocus, a motorized focusing mechanism that doesn't cause vibrations.

Burr started advertising his invention, he says, thinking that MotoFocus sales "would be a great way to have enough money to solve my fever problem — aperture fever, that is." He



Jim Burr, founder and president of JMI Telescopes, has been making telescopes for more than 30 years. courtesy Jim Burr

kept the TV shop's name and phone number, answering "Jim's Mobile," and thinking, "It'll either be television or telescopes."

The response to his invention was so favorable that Burr turned his hobby into a full-time venture in 1986, when he sold the TV business. JMI quickly became a highly respected manufacturer of amateur astronomical equipment.

"Business is good, and we have two people working all the overtime they want," Burr says. What more can you ask?

What products do you have on the market?

Today JMI makes the most compact, highly engineered MotoFocus available, fitting more than 200 models of telescopes. We also make MAX computers that can find 13,000 objects and are so easy to use that any 5-year-old could figure it out in 15 minutes; those also can be installed on more than 200 models of telescopes. Additionally, we have a line of beautiful molded cases, Wheeley Bars for transporting equipment, and high-quality focusers to replace cheap imports.

What's something cool and unusual about JMI?

The Jet Propulsion Laboratory (JPL) called in 2002, saying they needed a scope for NASA's Mars Science Lab. They were receiving data from Mars at 1 megabyte

per second using radio frequency, but they estimated data would go up to 100 megabytes per second using lasers.

You need telescopes for lasers, and after looking for 2 years they decided on our 25-inch NTT folded Newtonian. JPL purchased a second one in 2004.

After crunching the numbers, they decided they needed sixteen 30-inch versions. Unfortunately, they ran out of money and had to cancel the laser portion. Now the whole project has been postponed to 2011.

But that wasn't the last of our NTTs. In 2005, the MESSENGER spacecraft used them during tests while headed to Mercury. It was in June when they aimed the Mercury imaging laser back at Earth. I remember a call from JPL at the time, saying, "We have a free laser in space." What blew me away was that it was located

5° from Sirius, and they were going to fire a rather weak laser at 10 A.M., with the Sun nearby. They're happy with the results and think lasers are the future for getting data from space.

How has JMI changed through the years?

After establishing JMI as a full-time astronomy business, for years I worked on a new type of 18-inch telescope. In 1988, I hired Brian Rickard and Steve Innes to help me put the finishing touches on it and bring it to market. In early 1990, we sold the first NGT 18-inch, a revolutionary split-ring instrument. By the fall of 1991, we'd sold 50.

In 1992, JMI moved out of a four-car garage in Evergreen to Lakewood, Colorado. During the next 10 years, the office and manufacturing space expanded to 5 times its original size, and

in 2005 we moved to our present location in Lakewood.

What's your favorite way to observe the night sky?

Using binoculars is definitely the most exciting. I don't think people have any idea what large binos will do. I guarantee 10-inch binoculars will outdo a 25-inch reflector in deep space, having a higher contrast and giving a feeling of depth. I've tested 12-inch binoculars against a 30-inch reflector at the same power, and the 12-inch outperforms it hands down.

I'm not sure exactly why this is, but research indicates contrast goes up 40 times with binos, and I hear 10 percent of the brain doesn't fire unless both eyes are working. When you combine that with possible eye fatigue from viewing with one eye, binos just make more sense. ☛

The Cosmic Grid

All things high, low, weird, and wonderful in astronomy and space science. **by Bill Andrews and Liz Kruesi**

WEIRD



Behind the eyepiece

A photography exhibition in the United Kingdom features astronomers like Jocelyn Bell Burnell. Personally, I can't wait for the infrared images.



Great Scott!

Time-traveling Higgs bosons might be sabotaging CERN's Large Hadron Collider. No, seriously. "Otherwise distinguished physicists" say so.



Big Bang, big mess

The universe has more entropy than scientists previously suspected, so maybe your messy room isn't as bad as you thought.



Astro-spy

A NASA lunar scientist is arrested on espionage charges. Sounds like a mediocre Ian Fleming/Arthur C. Clarke collaboration.

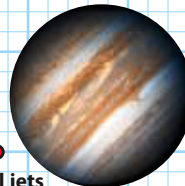


Go, go Galileo!

The Galileomobile begins its South American trip to bring astronomy education to the Andes, making it the coolest "mobile" since the Batmobile.

Virtual shmirtual

NASA encourages youngsters to take virtual space station spacewalks online. OK, either the Internet's changed a whole lot, or the definition of "virtual" has.



Jovial jets

An "inverse energy cascade" may be energizing Jupiter's jet streams. I'm not sure, but those sound like the kind of streams that shouldn't ever cross.



Pallas' promotion

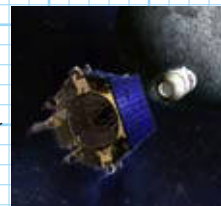
Asteroid Pallas is now considered a protoplanet, joining the ranks of Ceres and Vesta. All its rival asteroids now feel like amateurs.

Dollar doctor

A new Citigroup executive has a doctorate in astrophysics. Perfect — who better to deal with such astronomical numbers?

Lame LCROSS

NASA disappoints the general public when LCROSS's promised gigantic plume of lunar debris fails to appear. Or maybe that's just what the lunar spies want us to think.



HOT



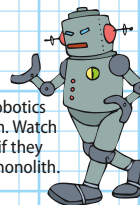
Top Tweeter

First astronaut on Twitter Mike Massimo has more than a million followers. NASA's plans of tricking the public into caring about space keep working.



The hole truth

Clark Planetarium creates a black-hole-themed planetarium show. Looks like the recession's started hitting the planetarium's light bulb budget.



Dig it!

NASA hosts a lunar robotics excavation competition. Watch out for those robots if they unearth a giant black monolith.



To infinity!

A Buzz Lightyear figurine receives a parade at Disney World after spending more than a year on the ISS. Remember when actual astronauts got parades?

Goodbye, Rosetta

ESA's comet-chaser Rosetta swings by Earth for the last time. Don't be too sad, everyone knows comet-chasers are only happy doing one thing.



iNASA

Love NASA's Astronomy Picture of the Day? There's an app for that.

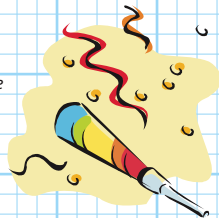
Ares carries on

NASA's preparations to convert to Ares rockets continue as scheduled. Not since Gemini have astrologers cheered so much for NASA.



Hoopy froods

It's been 30 years since *The Hitchhiker's Guide to the Galaxy* came out in print. Just another 12 years till the "big" celebration!



Good news, bad news

The risk of asteroid Apophis slamming into Earth in 2037 has been downgraded. But watch out in 2068! That possibility probably won't get downgraded for years!



Astronettes?

A look back at 50-year-old Air Force data shows women would have been equally good (or better) astronauts. Apparently sexism might have had some drawbacks — who knew?

NOT

PREDICTABLE

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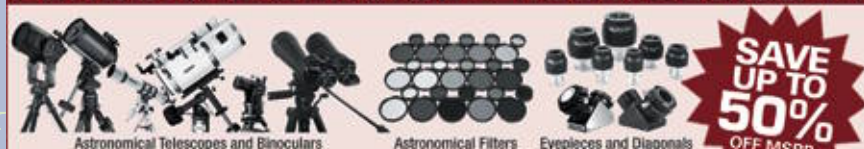
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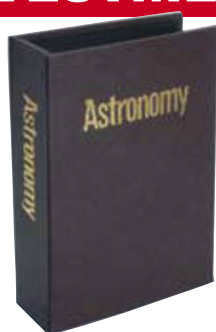
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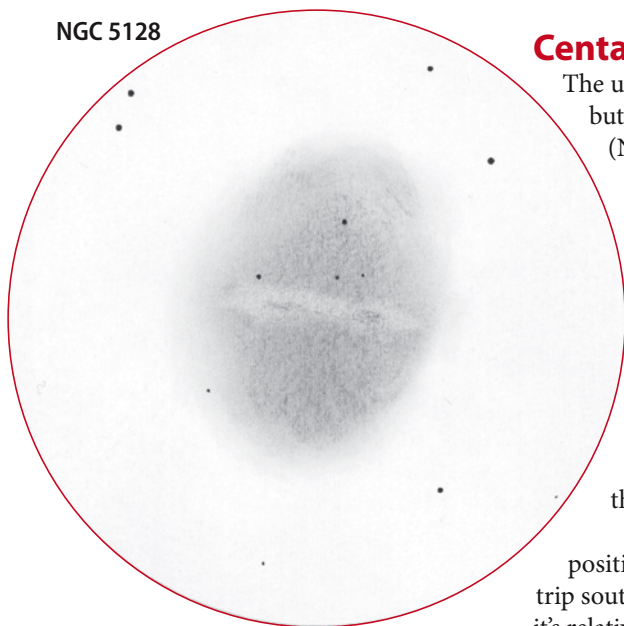
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Deep-sky Showcase

Astronomy's editor sketches two of his favorite objects. by David J. Eicher

Centaurus A and the Blackeye Galaxy

NGC 5128



Centaurus A sketched by David J. Eicher using a 17.5-inch f/4.5 reflector at 71x.

Centaurus A (NGC 5128)

The universe is full of freaky objects, but few are as weird as Centaurus A (NGC 5128). A giant galaxy that emits copious amounts of radio waves and other radiation, this object is a train wreck. Astronomers believe the odd form resulted from the ancient collision of two galaxies. They merged into this elliptical shell, setting off a violent round of star formation and “waking up” a supermassive black hole in the galaxy’s center.

Centaurus A is bright, but its position in the southern sky requires a trip south for many to see it well. When it’s relatively high in the sky, the galaxy is a treat for anyone armed with a 6-inch or larger scope. A 10-inch scope reveals fine

NGC 5128



Adam Block/NOAO/AURA/NSF

Designations: Centaurus A, NGC 5128
Position: 13h25m, -43°01' (2000.0)
Constellation: Centaurus
Type: S0 pec
Magnitude: 6.8
Size: 25.7' by 20.0'
Distance: 12.7 million light-years

detail in the galaxy’s halo. Through my 17.5-inch, I see the galaxy as a huge, bright haze in a rough egg shape, and the prominent central dust lane is easy to see. What’s amazing is that, at a distance of more than 5 times that of the Andromeda Galaxy (M31), it’s possible to see veins and knots of light in front of the dust — the eerie glow of stars winking on as gravity collapses gas and dust into a new generation of light.

M64



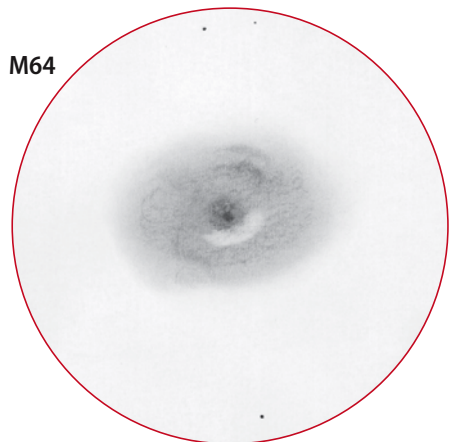
Designations: M64, NGC 4826
Position: 12h57m, 21°41' (2000.0)
Constellation: Coma Berenices
Type: Sb-
Magnitude: 8.5
Size: 10.0' by 5.4'
Distance: 31 million light-years

The Blackeye Galaxy (M64)

One of the brightest springtime galaxies in the great cloud that centers on the constellations Virgo and Coma Berenices, M64 is a visual treat through small scopes. On steady, moonless nights, you’ll see this galaxy’s oval glow quite easily through any telescope. With an 8-inch, you can see some nice detail. Called the Blackeye Galaxy because of its prominent, arcing dust lane set near the galaxy’s hub, this object is a showpiece for any springtime observer.

The Blackeye is a standard, run-of-the-mill Sb-type galaxy that has a bright center and smooth, broadly illuminated spiral arms. Through an 8-inch scope under a dark sky, you’ll see a nice hint of the spiral structure. Be sure to use a high-quality eyepiece, as the glass on your eye end is as important as the quality of the telescope’s mirror. Averted vision, the act

M64



The Blackeye Galaxy sketched by David J. Eicher using an 8-inch f/10 SCT at 170x.

of glancing slightly away from the object, will make the dark “eye” the galaxy is named for stand out more prominently than when looking directly at it. This galaxy will surely become a favorite. ☛

David J. Eicher is the editor of *Astronomy*. He has observed and sketched deep-sky objects for 33 years.



Encountering the counter glow

The “gegenschein,” or counter glow, is a spot in the sky at the antisolar point (opposite the Sun from Earth) that shines slightly brighter than the background. The gegenschein results when dust particles orbiting the Sun scatter light back to Earth. The gegenschein is brighter than the rest of the zodiacal light, of which it’s a part, because it lies directly opposite Earth and benefits from a higher angle of reflection of sunlight striking it. This image shows an area roughly 50° wide by 30° high. As a bonus, Uranus lies within the gegenschein.

The gegenschein (circled) (Canon EOS 20Da digital SLR, Nikon 24mm at f/2.8, ISO 1600, two 5-minute exposures stacked, taken September 20, 2009, at 1:24 A.M. EDT, from Cherry Springs, Pennsylvania) • **Jerry Lodriguss, Voorhees, New Jersey**



NGC 6781 in Aquila is a bubble of gas cast off by a single, formerly Sun-like star that has died. The bubble continues to expand. It currently measures some 2 light-years across. (16-inch RC Optical Systems Ritchey-Chrétien telescope at f/8.9, SBIG STL-6303M CCD camera, Hydrogen-alpha/Nitrogen-II/Oxygen-III image with 5-hour exposures through each filter) • **Keith B. Quattrocchi, Clovis, California**

reader gallery

➤ **Emission nebula IC 1795** is part of the larger Heart Nebula (IC 1805) in Cassiopeia. The small, bright nebula to the upper right is NGC 896. (16-inch RC Optical Systems Ritchey-Chrétien telescope at f/8.9, Apogee U16M CCD camera, 13 hours of exposures through Hydrogen-alpha, Oxygen-III, and Sulfur-II filters, and 4.5 hours of exposure through red, green, and blue filters) • **Don Goldman, Orangevale, California**

▼ **The Crescent Nebula** (NGC 6888) in Cygnus is a bubble of gas carved out of the interstellar medium by an incredibly energetic star known as a Wolf-Rayet star. That's the blue star shining at 7th magnitude at NGC 6888's center. (9-inch TMB folded apochromatic refractor, SBIG STL-11000 CCD camera, H α LRGB image with exposures of 20.78, 5.25, 15.89, 11, and 15.28 hours, respectively) • **Immo Gerber and Dietmar Hager, TAO Observatory, Provence, France**



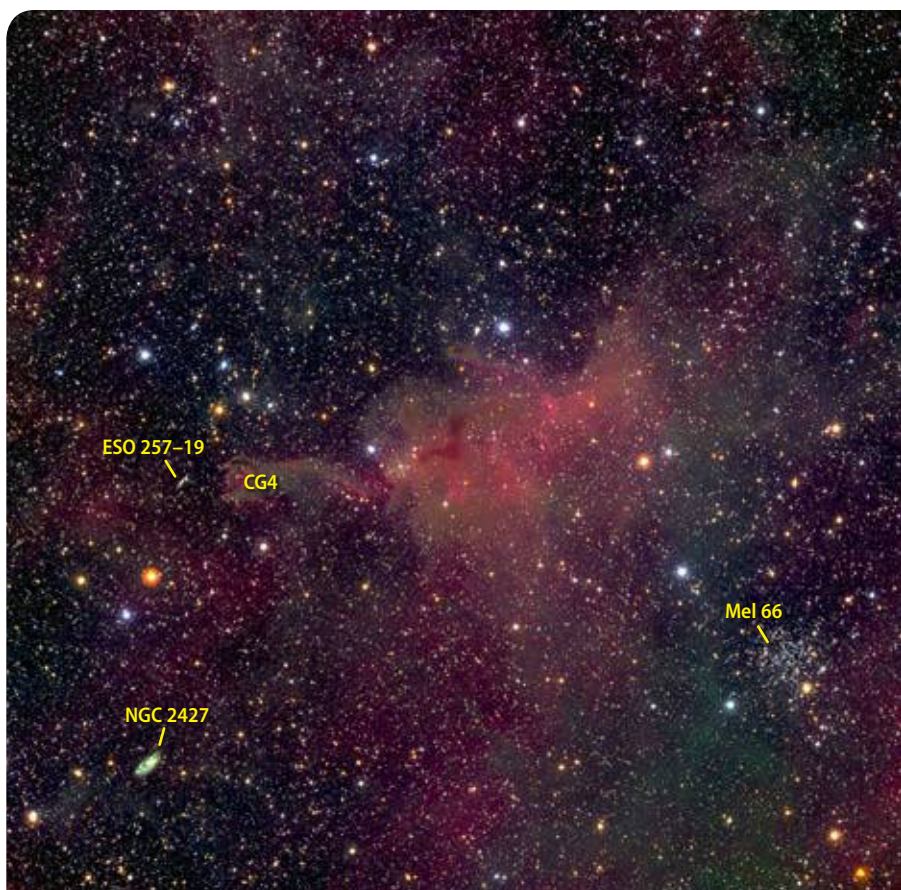


Open cluster M29 in Cygnus the Swan is one of the most difficult of Messier's objects to identify. It's a loose cluster of about two dozen stars lying in front of a rich Milky Way star field. (14.5-inch RC Optical Systems Ritchey-Chrétien telescope at f/7.9, SBIG STL-11000 CCD camera, LRGB image with exposures of 2,000, 600, 600, and 600 seconds, respectively)

• Richard Hammar, Springfield, Missouri



NGC 4372 is one of the sky's least concentrated globular clusters. At a distance of 15,000 light-years, it's a loose collection of mainly 12th- through 14th-magnitude stars. (3.2-inch Orion ED80 apochromatic refractor at f/7.5, Starlight Xpress SXV-H9 CCD camera, LRGB image with exposures of 30, 15, 15, and 15 minutes, respectively) • Michael Sidonio, Kotara, New South Wales, Australia



Cometary globular CG4 in Puppis lies in a rich region that includes magnitude 11.6 spiral galaxy NGC 2427, open cluster Melotte 66, and 14th-magnitude spiral ESO 257-19. (6.2-inch Astro-Physics apochromatic refractor at f/5.4, FLI KAF-16803 Proline CCD camera, LRGB image with exposures of 290, 100, 80, and 100 minutes, respectively)

• Thomas V. Davis, Inkom, Idaho



Three planets gathered in the early morning sky last October. The brightest, Venus, stood less than 6° to the upper right of Saturn and Mercury, which was the brighter of the pair. The imager took this shot while sitting

atop a boulder next to Georgian Bay. (Canon 50D digital SLR, 50mm lens at f/3.5, ISO 250, 2.6-second exposure, taken October 8, 2009, at 6:34 A.M. EDT, from Owen Sound, Ontario) • [Steve Irvine, Wiarton, Ontario](#)

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New!

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THE MOST SOPHISTICATED, EASIEST-TO-USE TELESCOPE ANYWHERE IS NOW AVAILABLE IN AN 8" APERTURE. THE LS-8 — ONLY FROM MEADE®

Meade ups the ante with the introduction of an 8 inch LightSwitch telescope. With 78% more light gathering power than the LS-6, the LS-8 turns a unique viewing experience into an unsurpassed viewing experience. And still, it's just as easy as flipping a switch.

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When Meade announced LightSwitch Technology in early 2009, the amateur astronomy game changed. Simply flip a switch and LightSwitch automatically aligns itself in the night sky. Built-in GPS, magnetic north sensors, level sensors and a CCD camera does all the work — within minutes your observing!

Astronomer Inside™

Let Meade's Astronomer Inside take you on a multi-media guided tour of the night sky. Choose the Tonight's Best tour and the Astronomer Inside automatically moves the telescope to the best objects in that night's sky. At each object, listen as the Astronomer Inside describes in detail, fascinating facts and history. Attach the optional video monitor and you now have a dazzling multi-media presentation that integrates rich audio and video. Or select your favorite object and your LS telescope takes you to it and tells you all about it. It's like having an astronomer at your side!

Meade Optics

Since 1972, Meade has consistently manufactured the finest optics available. Now you have your choice of either Meade's high-performance Schmidt-Cassegrain (SC) optics, or — for the truly discerning individual who demands the very best — Meade's Advanced Coma-Free™ (ACF) optical system delivering the sharpest, brightest image available. Both systems are made with superior materials featuring Schott® water white glass front correctors, oversized Pyrex® primary mirrors and include Meade's UHTC™ coatings for optimum light transmission. Either way, you get Meade's legendary optics.

Finding out more about the new LS-8 is almost as easy as using one — just go to www.meade.com.

LS-8 ACF - \$1,999 • LS-8 SC - \$1,799

LS-6 ACF - \$1,499 • LS-6 SC - \$1,399

**Optional LS 3.5" Color LCD Video Monitor \$99*

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